CHAPTER 11

PACIFIC OCEAN PERCH

by

Paul D. Spencer and James N. Ianelli

Executive Summary

The following changes were made to the Pacific Ocean Perch (POP) assessment relative to the November 2002 SAFE:

Changes in the Input Data

(1) The 2002 harvest level has been revised and harvests through September 27, 2003 have been included in the assessment.

(2) The 2002 length composition from the Aleutian Islands (AI) fishery was included in the assessment.

(3) The 2002 age composition from the Aleutian Islands (AI) survey was included in the assessment.

Changes in the Assessment Methodology

1) A Monte-Carlo Markov Chain algorithm was used to obtain estimates of uncertainty of modeled quantities.

Changes in the Assessment Results

(1) A summary of the 2003 assessment recommended ABC's relative to the 2002 recommendations is as follows:

	Assessment Year	
	2002	2003
ABC	15,071 t	13,297 t
OFL	17,856 t	15,761 t

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SSC comments on rockfish harvest policy

The April, 2003, SSC minutes note that the SSC discussed "*whether a more conservative harvest rate (F50%) would be desirable for rockfish species in the GOA and BSAI*", and specifically requested that "*stock assessment analysts evaluate the harvest strategy for rockfishes during the TAC-setting process this fall.*"

An additional harvest policy evaluation that incorporated process error and measurement error as described in the Programmatic Supplemental Environmental Impact Statement bookend 3b was included in the assessment. The methodology was to apply an uncertainty factor to $F_{35\%}$ in order to produce an alternative F_{abc}, which would be used if it was lower than F_{abc} produced under the status quo harvest policy. However, the uncertainty factor was sufficiently large that the alternative F_{abc} was not lower than F_{abc} produced from the status quo harvest policy. Additional harvest policy evaluations will be prepared for the December meeting of the SSC.

INTRODUCTION

Pacific ocean perch (*Sebastes alutus*) inhabit the outer continental shelf and upper slope regions of the North Pacific Ocean and Bering Sea. Pacific ocean perch, and four other associated species of rockfish (northern rockfish, *S. polyspinis*; rougheye rockfish, *S. aleutianus*; shortraker rockfish, *S. borealis*; and sharpchin rockfish, *S. zacentrus*) were managed as a complex in the two distinct areas from 1979 to 1990. Known as the POP complex, these five species were managed as a single entity with a single TAC (total allowable catch). In 1991, the North Pacific Fishery Management Council separated POP from the other red rockfish in order to provide protection from possible overfishing. Of the five species in the former POP complex, *S. alutus* has historically been the most abundant rockfish in this region and has contributed most to the commercial rockfish catch.

Since 2001, POP in the Bering Sea-Aleutian Islands area have been assessed and managed as a single stock. Motivations for this change includes the paucity of data in the EBS upon which to base an age-structured assessment, and uncertainty that the EBS POP represent a discrete stock (Spencer and Ianelli 2001).

Information on Stock Structure

A variety of types of research can be used to infer stock structure of POP, including age and length compositions, growth patterns and other life-history information, and genetic studies. Spatial differences in age or length compositions can be used to infer differences in recruitment patterns that may correspond to population structure. In Queen Charlotte Sound, British Columbia, Gunderson (1972) found substantial differences in the mean lengths of POP in fishery hauls taken at similar depths which were related to differences in growth rates and concluded that Pacific ocean perch (POP) likely form aggregations with distinct biological characteristics. In a subsequent study, Gunderson (1977) found differences in size and age composition between Moresby Gully and two other gullies in Queen Charlotte Sound. Westrheim (1970, 1973) recognized “British Columbia” and “Gulf of Alaska” POP stocks off the western coast of Canada based upon spatial differences in length frequencies, age frequencies, and growth patterns observed from a trawl survey. In a study that has influenced management off Alaska, Chikuni (1975) recognized distinct POP stocks in four areas – eastern Pacific (British Columbia), Gulf of Alaska, Aleutian Islands, and Bering Sea. However, Chikuni (1975) states that the eastern Bering Sea (EBS) stock likely receives larvae from both the Gulf of Alaska (GOA) and Aleutian Islands (AI) stock, and the AI stock likely receives larvae from the GOA stock.

Stock differentiation occurs from separation at key life-history stages, and another approach to evaluating stock structure involves examination of rockfish life-history stages directly. Because many rockfish species are not thought to exhibit large-scale movements as adults, movement to new areas and boundaries of discrete stocks may depend largely upon the pelagic larval and juvenile life-history stages.

In 2002, an analysis of archived *Sebastes* larvae was undertaken by Dr. Art Kendall; using data collected in 1990 off southeast Alaska (650 larvae) and the AFSC ichthyoplankton database (16,895 *Sebastes* larvae, collected on 58 cruises from 1972 to 1999). The southeast Alaska larvae all showed the same morph, and were too small to have characteristics that would allow species identification. A preliminary examination of the AFSC ichthyoplankton database indicates that most larvae were collected in the spring, the larvae were widespread in the areas sampled, and most are small (5-7 mm). The larvae were organized into three size classes for analysis: <7.9 mm, 8.0-13.9 mm, and >14.0 mm. A subset of the abundant small larvae was examined, as were all larvae in the medium and large groups. Species identification based on morphological characteristics is difficult because of overlapping characteristics among species, as few rockfish species in the north Pacific have published descriptions of the complete larval developmental series. However, all of the larvae examined could be assigned to four morphs identified by Kendall (1991), where each morph is associated with one or more species. Most of the small larvae examined belong to a single morph, which contains the species *S. alutus* (POP), *S. polyspinus* (northern rockfish), and *S. ciliatus* (dusky rockfish). Some larvae belonged to a second morph which has been identified as *S. borealis* (shortraker rockfish) in the Bering Sea.

Rockfish identification can be aided by studies that combine genetic and morphometric techniques and information has been developed to identify individual species based on allozymes (Seeb and Kendall 1991) and mitochondrial DNA (Gharrett et al. 2001, Rocha-Olivares 1998). The Ocean Carrying Capacity (OCC) field program, conducted by the Auke Bay laboratory, uses surface trawls to collect juvenile salmon and incidentally collects juvenile rockfish. These juvenile rockfish are large enough (approximately 25 mm and larger) to allow extraction of a tissue sample for genetic analysis without impeding morphometric studies. In 2002, species identifications were made for an initial sample of 55 juveniles with both morphometric and genetic techniques. The two techniques showed initial agreement on 39 of the 55 specimens, and the genetic results motivated re-evaluation of some of the morphological species identifications. Forty of the specimens were identified as POP, and showed considerably more morphological variation for this species than previously documented. Given the success of this initial examination of the OCC data with these techniques, a more comprehensive study is planned for the near future.

Because stocks are, by definition, reproductively isolated population units, it is expected that different stocks would show differences in genetic material due to random drift or natural selection. Thus, analysis of genetic material from north Pacific rockfish is currently an active area of research.

Seeb and Gunderson (1988) used protein electrophoresis to infer genetic differences based upon differences in allozymes from POP collected from Washington to the Aleutian Islands. Discrete genetic stock groups were not observed, but instead gradual genetic variation occurred that was consistent with an isolation by distance model. The study included several samples in Queen Charlotte Sound where Gunderson (1972, 1977) found differences in size compositions and growth characteristics. Seeb and Gunderson (1988) concluded that the gene flow with Queen Charlotte Sound is sufficient to prevent genetic differentiation, but adult migrations were insufficient to prevent localized differences in length and age compositions. However, recent studies of POP using microsatellite DNA indicate population structure at small spatial scales, consistent with the work of Gunderson (1972, 1977), and suggest that adult POP do not migrate far from their natal grounds and larvae are entrained by currents in localized retention areas (Withler et al. 2001).

Interpretations of stock structure are influenced by the particular genetic analysis conducted, as illustrated by the differing conclusions produced from the POP allozyme work of Seeb and Gunderson (1988) and the microsatellite work of Withler et al. (2001); note that these two components of the genome diverge on very different time scales and that, in this case, microsatellites are much more sensitive. Protein electrophoresis examines DNA variation only indirectly via allozyme frequencies, and does not recognize situations where differences in DNA may result in identical allozymes (Park and Moran 1994). In addition, many microsatellite loci may be selectively neutral or near-neutral, whereas allozymes are central metabolic pathway enzymes and do not have quite the latitude to produce viable mutations. The mutation rate of microsatellite alleles can be orders of magnitude higher than allozyme locus mutation rates. Most current studies on rockfish genetic population structure involve direct examination of either mitochondrial DNA (mtDNA) or microsatellite DNA.

A recent analysis by Dr. Anthony Gharrett of the Juneau Center of Fisheries and Ocean Sciences examined the mtDNA for POP samples collected in the GOA and BSAI, and conducted a preliminary analysis of POP microsatellite variation in these regions. The POP mtDNA analysis was performed on 124 fish collected from six regions ranging from southeast Alaska to the Bering Sea slope and central Aleutian Islands. No population structure was observed, as most fish (102) were characterized by a common haplotype. However, the preliminary work with 10 microsatellite loci from the six regions resulted in 7 loci with significant heterogeneity in the distribution of allele frequencies. Additionally, the sample in each region was distinct from those in adjacent regions, suggesting population structure on a relatively fine spatial scale consistent with the results on Gunderson (1972, 1977) and Wither et al. (2001). Ongoing genetic research with POP is focusing on increasing the sample sizes and collection sites for the microsatellite analysis in order to further refine our perception of stock structure.

FISHERY

Pacific ocean perch were highly sought by Japanese and Soviet fisheries and supported a major trawl fishery throughout the 1960s. Catches in the eastern Bering Sea peaked at 47,000 (metric tons, t) in 1961; the peak catch in the Aleutian Islands region occurred in 1965 at 109,100 t. Apparently, these stocks were not productive enough to support such large removals. Catches continued to decline throughout the 1960s and 1970s, reaching their lowest levels in the mid 1980s. With the gradual phase-out of the foreign fishery in the 200-mile U.S. Exclusive Economic Zone (EEZ), a small joint-venture fishery developed but was soon replaced by a domestic fishery by 1990. In 1990 the domestic fishery recorded the highest Pacific ocean perch removals since 1977. The history of *S. alutus* landings since implementation of the Magnuson Fishery Conservation and Management Act (MFCMA) is shown in Table 11.1.

Estimates of retained and discarded Pacific ocean perch from the fishery have been available since 1990 (Table 11.2). The eastern Bering Sea region generally shows a higher discard rate than in the Aleutian Islands region. For the period from 1990 to 2002, the Pacific ocean perch discard rate in the eastern Bering Sea averaged about 25%, and the 2002 discard rate was 56%. In contrast, the discard rate from 1990 to 2002 in the Aleutian Islands averaged about 14%, with an 2002 discard rate of 12%. The removals from trawl and hydoracoustic surveys are shown in Table 11.3.

There has been little change in the distribution of observed Aleutian Islands POP catch with respect to fishing depth and management area (based on observer records) between the broad periods covering the foreign and joint venture fisheries (years 1977-1988) and the domestic fishery (years 1990-2002). The fishing depth accounting for the largest proportion of catch in each fishery was 200-299 m, with 49% and 65% of the observed foreign/joint venture and domestic catch, respectively (Table 11.4). Management area 541 contributes the largest share of the observed catch in each fishery; with 46% and 41% in the foreign/joint venture and domestic fisheries, respectively (Table 11.5). In contrast, area 543 contributes the largest share of the catch in the 2002 fishery due to the spatial allocation of harvest quotas. Although the catch by management area between the two time periods was similar, variations appeared to occur within each of these periods. For example, area 543 contributed a large share of the catch in the late 1970s foreign fishery, as well as the domestic fishery from the mid-1990s to the present. In the late 1980s to the early 1990s, area 541 contributed a large share of the catch, and prompted management changes to spatially allocate POP harvest. Note that the extent to which the patterns of observed catch can be used as a proxy for patterns in total catch is dependent upon the degree to which the observer sampling represents the true fishery. In particular, the proportions of total POP caught that were actually sampled by observers were very low in the foreign fishery, due to low sampling ratio prior to 1984 (Megrey and Wespestad 1990).

DATA

Fishery Data

Catch per unit effort (CPUE) data from Japanese trawl fisheries indicate that Pacific ocean perch stock abundance has declined to very low levels in the Aleutian Islands region (Ito 1986). By 1977, CPUE values had dropped by more than 90-95% from those of the early 1960s. Japanese CPUE data after 1977, however, is probably not a good index of stock abundance because most of the fishing effort has been directed to species other than Pacific ocean perch. Standardizing and partitioning total groundfish effort into effort directed solely toward Pacific ocean perch is extremely difficult. Increased quota restrictions, effort shifts to different target species, and rapid improvements in fishing technology undoubtedly affect our estimates of effective fishing effort. Consequently, we included CPUE data primarily to evaluate its consistency with other sources of information. We used nominal CPUE data for class 8 trawlers in the eastern Bering Sea and Aleutian Islands regions from 1968-1979. During this time period these vessels were known to target on Pacific ocean perch (Ito 1982).

Length measurements and otoliths read from the EBS and AI management areas were combined to create fishery age/size composition matrices (Table 11.6). Years which were not selected for age or length compostion were rejected due to low samples sizes of fish measured (<300; years 1973-1976, 1985-1986), and/or otoliths read (<150; years 1984, 1987, 1989). In 1982, the method for aging otoliths at the Alaska Fisheries Science Center changed from surface reading to the break and burn method (Betty Goetz, Alaska Fisheries Science Center, pers. comm.), as the latter method is considered more accurate for older fish (Tagart 1984). The time at which the otoliths collected from 1977 to 1982 were read is not known for many vessels and cruises. However, the information available suggests that otoliths from 1977 to 1980 were read prior to 1981, whereas otoliths from 1981 and 1982 were read after 1982.

Survey Data

The Aleutian Islands survey biomass estimates were used as an index of abundance for the BSAI POP stock. Note that there is wide variability among survey estimates from the portion of the southern Bering Sea portion of the survey (from 165 W to 170 W), as the post-1991 coefficients of variation (CVs) range from 0.41 to 0.64 (Table 11.7). The biomass estimates in this region increased from 1,501 t in 1991 to 18,217 t in 1994; the 2002 estimate is 16,311 t. The estimated biomass of Pacific ocean perch in the Aleutian Islands management area region (170^{o} W to 170^{o} E) appears to be less variable, with CVs ranging from 0.16 to 0.24. For the entire survey area, there has been a steady increase from 1980 to 1997, followed by declines to the 2000 and 2002 estimates. The 1991 trawl survey produced a biomass estimate of 351,093 t, more than three times the 1980 point estimate. The 1994 and 1997 trawl surveys produced biomass estimates of 383,618 and 625,272 t. Since 1997, the trawl survey estimates declined from 511,706 t in 2000 and 468,588 t in 2002. Age composition data exists for each survey. The length measurements and otoliths read from the Aleutian Islands surveys are shown in Table 11.8.

Historically, the Aleutian Island survey have indicated higher abundances in the western and central Aleutian Islands, and this pattern was repeated in the 2002 survey (Figure 11.1). In particular, areas near Stalemate Bank, Tahoma Bank-Buldir Island, and Kiska Island showed high CPUE in 2002 survey tows.

The 2002 EBS slope survey represents the initiation of a new biennial survey. The most recent slope survey prior to 2002, excluding some preliminary tows in 2000 intended for evaluating survey gear, was in 1991, and previous slope survey results have not been used in the BSAI model due to high CVs, relatively small population sizes compared to the AI biomass estimates, and lack of recent surveys. The 2002 EBS slope survey POP biomass estimate and its standard deviation were 76,685 t and 38,589 t, resulting in a CV of 0.53. A plot of the survey CPUE per haul reveals a large number of hauls with no catch mixed with few hauls with sizable catches, with one haul southwest of the Pribilof Islands having an especially large catch (Figure 11.2). The 2002 EBS slope survey results are not used in this assessment, and the feasibility of incorporating this time series will be evaluated in future years.

The following table summarizes the data available for the BSAI POP model:

Component	BSAI
Fishery catch	1960-2003
Fishery age composition	1977-82, 1990,1998,2000,2001
Fishery size composition	1964-72, 1983-1984,1987-1989,1991-1997,1999,2002
Fishery CPUE	1968-79
Survey age composition	1980, 83, 86, 91, 94, 97, 2000,2002
Survey biomass estimates	1980, 83, 86, 91, 94, 97, 2000, 2002

Biological Data

The surveys produce large numbers of samples for age determination, length-weight relationships, sex ratio information, and for estimating the length distribution of the population. The age compositions were determined by constructing age-length keys for each year and using them to convert the observed length frequencies from each year. Because the survey age data were based on the break and burn method of ageing Pacific ocean perch, they were treated as unbiased but measured with error. Kimura and Lyons (1991) give data on the percent agreement between otolith readers for Pacific ocean perch. The estimate of aging error was identical to that presented in Ianelli and Ito (1991). The assessment model uses this information to create a transition matrix to convert the simulated "true" age composition to a form consistent with the observed but imprecise age data.

Assessments of Pacific ocean perch have improved significantly because of improved methods of age determination. Historically, Pacific ocean perch age determinations were done using scales and surface readings from otoliths. These gave estimates of natural mortality of about 0.15 and longevity of about 30 years (Gunderson 1977). Based on the now accepted break and burn method of age determination using otoliths, Chilton and Beamish (1982) determined the maximum age of *S. alutus* to be 90 years. Using similar information, Archibald et al. (1981) concluded that natural mortality for Pacific ocean perch should be on the order of 0.05.

Aleutian Islands survey data from years 1980, 1983, 1986, 1991, 1994, and 1997, and eastern Bering Sea survey data from 1981, 1982, and 1991, were used to estimate von Bertalannfy growth curves. The resulting growth curves are:

	Aleutian Islands	**Eastern Bering Sea**
L_{inf}	40.09	40.38
K	0.1629	0.1323
t_0	-0.72855	-1.7766

There is little difference in the growth curves between areas, or in the estimated growth curves within an area over time. Growth information from the Aleutian Islands was used to convert estimated numbers at age within the model to estimated numbers at length.

The estimated length(cm)-weight(g) relationship for Aleutian Islands POP was estimated with survey information from the same years. For the eastern Bering Sea, fishery data from 1975 to 1999 were used to estimate the length-weight relationship, as individual weights were not recorded in the EBS surveys. The resulting length-weight relationships, where weight = a*(length)^b, were similar between regions:

	Aleutian Islands	Eastern Bering Sea
a	1.054×10^{-5}	8.59×10^{-6}
b	3.08	3.13

Again, there was little difference between areas, or between years in a single area. The Aleutian Islands length-weight relationship was used to produce estimated weights at age. A combined-sex model was used, as the ratio of males to females varied slightly from year to year but was not significantly different from 1:1 (Ianelli and Ito 1991). The proportion mature at age schedule used is identical to that used in the Gulf of Alaska POP assessment.

ANALYTIC APPROACH

Model Structure

An age-structured population dynamics model, implemented in the software program ADModelbuilder, was used to obtain estimates of recruitment, numbers at age, and catch at age. Population size in numbers at age *a* in year *t* was modeled as

$$N_{t,a} = N_{t-1,a-1} e^{-Z_{t-1,a-1}} \qquad 3 \le a < A, \quad 1960 \le t \le T$$

where Z is the sum of the instantaneous fishing mortality rate ($F_{t,a}$) and the natural mortality rate (M), A is the maximum number of age groups modeled in the population (defined as 25), and T is the terminal year of the analysis (defined as 2003). The numbers at age A are a "pooled" group consisting of fish of age A and older, and are estimated as

$$N_{t,A} = N_{t-1,A-1} e^{-Z_{t-1,A-1}} + N_{t-1,A} e^{-Z_{t-1,A}}$$

The numbers at age in the first year are estimated as

$$N_a = R_0 e^{-M(a-3)+\gamma_a}$$

where R_0 the number of age 3 recruits for an unfished population and γ is an age-dependant deviation assumed to be normally distributed with mean of zero and a standard deviation equal to the recruitment standard deviation (σ). The previous stock synthesis model estimated the first year numbers at age to be in equilibrium with an historical catch of 400 t, and required estimation of a historic fishing mortality rate parameter. The equilibrium assumption implied that the recruitment strengths of all cohorts in the first year were equivalent, whereas the estimation of the vector of age-dependant deviations from average recruitment allows estimation of year class strength.

The total numbers of age 3 fish from 1960 to 1996 are estimated as parameters in the model, and are modeled with a lognormal distribution

$$N_{t,3} = e^{(\mu_R + \nu_t)}$$

where ν is a time-variant deviation. The recruitments from 1997 to 2003 are set the median recruitment, e^{μ_r}.

The fishing mortality rate for a specific age and time ($F_{t,a}$) is modeled as the product of a fishery age-specific selectivity (*fishsel*) and a year-specific fully-selected fishing mortality rate *f*. The fully selected mortality rate is modeled as the product of a mean (μ_f) and a year-specific deviation (ϵ_t), thus $F_{t,a}$ is

$$F_{t,a} = fishsel_a * f_t \equiv fishsel_a * e^{(\mu_f + \varepsilon_t)}$$

Given the similarity between the two fisheries in terms of depth and management area fished (Tables 11.4 and 11.5), a single fishery selectivity curve was used. A double logistic fishery selectivity curve been used in some previous assessments, as an asymptotic selectivity pattern for the fishery was originally found to be inadequate in describing the observed data (Ianelli and Ito 1992). A variety of fishery selectivity curves were evaluated in the 2001 assessment (Spencer and Ianelli 2001), with the asymptotic fishery selectivity curve chosen as the preferred model.

The mean numbers at age for each year was computed as

$$\overline{N}_{t,a} = N_{t,a} * (1 - e^{-Z_{t,a}}) / Z_{t,a}$$

The predicted length composition data were calculated by multiplying the mean numbers at age by a transition matrix, which gives the proportion of each age (rows) in each length group (columns); the sum across each age is equal to one. Twenty-five length bins were used, ranging from 15 cm to 39+ cm. The transition matrix was based upon an estimated von Bertalanffy growth relationship, with the variation in length at age interpolated from between the first and terminal ages in the model.

Both unbiased and biased age distributions are used in the model. For unbiased age distributions, aging imprecision is inferred from studies indicating that the percent agreement between readers varies from 60% for age 3 fish to 13% for age 25 fish (Kimura and Lyons 1991). The information on percent agreement was used to derive the variability of observed age around the “true”age, assuming a normal distribution. The mean number of fish at age available to the survey or fishery is multiplied by the aging error matrix to produce the observed survey or fishery age compositions. Similarly, estimated biased age distributions are computed by multiplying the mean number of fish at age by a biased aging error matrix, which was derived from data in Tagart (1984).

Catch biomass at age was computed as the product of mean numbers at age, instantaneous fishing mortality, and weight at age. The predicted trawl survey biomass (*pred_biom*) was computed as

$$pred\_biom_t = qsurv \sum_a \left(\overline{N}_{t,a} * survsel_a * W_a \right)$$

where W_a is the population weight at age, $survsel_a$ is the survey selectivity, and *qsurv* is the trawl survey catchability. We use the Aleutian Islands trawl survey biomass estimates in a relative sense rather than in an absolute sense by allowing *qsurv* to be estimated in the model rather than fixed at 1.0. Similarly, the predicted catch per unit effort index was computed as

$$pred\_cpue_t = qcpue \sum_a \left(\overline{N}_{t,a} * fishsel_a * W_a \right)$$

where *qcpue* is the scaling factor for the CPUE index.

Parameters Estimated Independently

The parameters estimated independently include the biased and unbiased age error matrices, the age-length transition matrix, individual weight at age, and natural mortality. The age error matrices were obtained from information in Kimura and Lyons (1991) and Tagart (1984), and are identical to those used in the previous assessments. The age-length transition matrix was derived from the von Bertalanffy growth parameters discussed above, which were combined with the length-weight relationship to obtain estimates of individual weights. The natural mortality rate *M* was fixed at 0.05, consistent with studies on POP age determination (Chilton and Beamish 1982, Archibald et al. 1981). The standard deviation of log recruitment (σ) was fixed, as the estimation of variance parameters could increase the potential for model instability, and a variety of choices were evaluated.

Parameters Estimated Conditionally

Parameter estimation is facilitated by comparing the model output to several observed quantities, such as the age and length composition of the survey and fishery catch, the survey biomass, and the catch biomass. The general approach is to assume that deviations between model estimates and observed quantities are attributable to observation error and can be described with statistical distributions. Each data component provides a contribution to a total log-likelihood function, and parameter values that maximize the log-likelihood are selected.

The log-likelihood of the initial recruitments were modeled with a lognormal distribution

$$\lambda_1 \left[\sum_t \frac{\left(\nu_t + \frac{\sigma^2}{2} \right)^2}{2\sigma^2} + n\ln(\sigma) \right]$$

The adjustment of adding $\sigma^2/2$ to the deviation was made in order to produce deviations from the mean, rather than the median, recruitment.

The log-likelihoods of the fishery and survey age and length compositions were modeled with a multinomial distribution. The log of the multinomial function (excluding constant terms) for the fishery length composition data, with the addition of a term that scales the likelihood, is

$$n_{f,t,l} \sum_{s,t,l} p_{f,t,l} \ln(\hat{p}_{f,t,l}) - p_{f,t,l} \ln(p_{f,t,l})$$

where *n* is the square root of the number of fish measured, and $p_{f,t,l.}$ and $\hat{p}_{f,t,l}$ are the observed and estimated proportion at length in the fishery by year and length. The likelihood for the age and length proportions in the survey, $p_{surv,t,a}$ and $p_{surv,t,l}$, respectively, follow similar equations.

The log-likelihood of the survey biomass was modeled with a lognormal distribution:

$$\lambda_2 \sum_t (\ln(obs\_biom_t) - \ln(pred\_biom_t))^2 / 2cv_t^2$$

where obs_biom_t is the observed survey biomass at time t, cv_t is the coefficient of variation of the survey biomass in year t, and λ_2 is a weighting factor. The log-likelihood of the CPUE index is computed in a similar manner, and is weighted by λ_3. The log-likelihood of the catch biomass was modeled with a lognormal distribution:

$$\lambda_4 \sum_t (\ln(obs\_cat_t) - \ln(pred\_cat_t))^2$$

where obs_cat_t and $pred\_cat_t$ are the observed and predicted catch. Because the catch biomass is generally thought to be observed with higher precision that other variables, λ_4 is given a very high weight so as to fit the catch biomass nearly exactly. This can be accomplished by varying the F levels, and the deviations in F are not included in the overall likelihood function. The overall negative log-likelihood function is

$$\begin{aligned}
&\lambda_1 \left(\sum_t \left(\frac{\nu_t + \sigma^2/2}{2\sigma^2} \right)^2 + n\ln(\sigma) \right) + \\
&\lambda_2 \sum_t (\ln(obs_biom_t) - \ln(pred_biom_t))^2 / 2 * cv_t^2 + \\
&\lambda_3 \sum_t (\ln(obs_cpue_t) - \ln(pred_cpue_t))^2 / 2 * cv_{CPUE}^2 + \\
&n_{f,t,l} \sum_{s,t,l} p_{f,t,l} \ln(\hat{p}_{f,t,l}) - p_{f,t,l} \ln(p_{f,t,l}) + \\
&n_{f,t,a} \sum_{s,t,l} p_{f,t,a} \ln(\hat{p}_{f,t,a}) - p_{f,t,a} \ln(p_{f,t,a}) + \\
&n_{surv,t,a} \sum_{s,t,a} p_{surv,t,a} \ln(\hat{p}_{surv,t,a}) - p_{surv,t,a} \ln(p_{surv,t,a}) + \\
&n_{surv,t,l} \sum_{s,t,a} p_{surv,t,l} \ln(\hat{p}_{surv,t,l}) - p_{surv,t,l} \ln(p_{surv,t,l}) + \\
&\lambda_4 \sum_t (\ln(obs_cat_t) - \ln(pred_cat_t))^2
\end{aligned}$$

For the model run in this analysis, λ_1, λ_2, λ_3, and λ_4 were assigned weights of 1,1, 0.5, and 500, reflecting a de-emphasis of the CPUE index and strong emphasis on fitting the catch data. The sample sizes for the age and length compositions were set to the square root of the number of fish measured or otoliths read. The negative log-likelihood function was minimized by varying the following parameters:

Parameter type	Number
1) fishing mortality mean (μ_f)	1
2) fishing mortality deviations (ϵ_t)	44
3) recruitment mean (μ_r)	1
4) recruitment deviations (ν_t)	37
5) historic recruitment (R_0)	1
6) first year recruitment deviations	22
7) Biomass survey catchability	1
8) CPUE index catchability	1
9) fishery selectivity parameters	2
10) survey selectivity parameters	2
Total parameters	112

Finally, a Monte Carlo Markov Chain (MCMC) algorithm was used to obtain estimates of parameter uncertainty (Gelman et al. 1995). One million MCMC simulations were conducted, with every 1,000th sample saved for the sample from the posterior distribution. Ninety-five percent confidence intervals were produced as the values corresponding to the 5th and 95th percentiles of the MCMC evaluation. For this assessment, confidence intervals on total biomass, spawning biomass, and recruitment strength are presented.

RESULTS

Model Selection

In order to evaluate the effect of σ, a series of models in which σ was fixed at either 0.5, 0.75, or 1.0 were evaluated (Table 11.9). The recruitment likelihood component had a higher negative log-likelihood as σ increased, accounting for some of the changes in the overall model fit. The fit to the fishery biased age compositions degraded as σ increased, whereas the fit to the fishery length compositions improved as σ increased. A run eliminating the recruitment component of the likelihood function was also evaluated, and gave a lower negative log-likelihood than fixing σ at 0.75. However, the lack of any constraints on recruitment in this model resulted in the estimated population in the first year of the model to consist predominately of age 9 fish. Additionally, the estimated Hessian matrix was not positive definite, indicating instability in the model fit. Overall, the model with σ = 0.75 had the lowest negative log-likelihood of the models with a fixed σ and was chosen as the preferred model, and the results below refer to this base case.

The fit to the age and size composition data can be inferred from the comparison of the average input sample sizes (set to square root of the number of samples), by data type, to the effective sample size (Table 11.9). The effective sample size can be interpreted as the sample size that would be consistent with the fit produced by the model, and data components where the effective sample size exceeds the input sample size can be interpreted as good fits. The average effective sample size for all age and length composition components of the likelihood exceeds their average input sample weights. In particular, the average effective sample size for the fishery length composition was approximately 80% larger than the average input sample weights, and had the largest effective sample size.

Biomass Trends

The estimated survey biomass index begins with 838,436 t in 1960, declines to 116,714 t in 1978, and increases to 505,094 t in 1995 and remains at approximately that level, with a 2003 estimate of 495,133 t (Figure 11.3). The survey point estimates are used in a relative sense rather than in an absolute sense, with a survey catchability (q) estimated at 1.59 rather than fixed at 1.0. Because the Aleutian Islands survey biomass estimates are taken as an index for the entire BSAI area, it is reasonable to expect that the q would be below 1.0 to the extent that the total BSAI biomass is higher than the Aleutian Islands biomass. One factor that may cause an increase in survey catchability is the expansion of survey trawl estimates to untrawlable areas (Kreiger and Sigler 1996). The fit to the CPUE index is shown in Figure 11.4.

The total biomass showed a similar trend as the survey biomass, with the 2003 total biomass estimated as 348,690 t. The estimated time series of total biomass and spawning biomass, with 95% confidence intervals obtained from MCMC integration, are shown in Figure 11.5. Total biomass, spawning biomass, and recruitment are given in Table 11.10. The estimated numbers at age are shown in Table 11.11.

Age/size compositions

The fishery age compositions, biased and unbiased, are shown in Figures 11.6 and 11.7 respectively. The observed proportion in the binned age 25+ group for years 1981 and 1982 is higher than the estimated proportion, although the fits improve in recent years (Figure 11.8). The fishery length compositions are shown in Figure 11.8; some of the lack of fit in the mid- to late-1980s is attributable to the low sample size of lengths observed from a reduced fishery. The survey age compositions (Figure 11.9) show a similar pattern as the unbiased fishery age compositions in that the age 25+ group is fit better in recent years (1994-2002) than earlier years (1980-1986). The estimated age at 50% selection for the survey and fishery selectivity curves were 5.17 and 6.66 years, respectively (Figure 11.10).

Fishing Mortality

The estimates of instantaneous fishing mortality for POP range from highs during the 1970’s to low levels in the 1980’s (Figure 11.11). Relative to the estimated $F_{35\%}$ level, BSAI POP were overfished during considerable portions of this period. Fishing mortality rates since the early 1980's, however, have moderated considerably due to the phase out of the foreign fleets and quota limitations imposed by the North Pacific Fishery Management Council. The average fishing mortality from 1965 to 1980 was 0.26, whereas the average from 1981 to 2002 was 0.03.

Recruitment

For both the eastern Bering Sea and Aleutian Islands, year class strength varies widely (Figure 11.12; Table 11.10). The relationship between spawning stock and recruitment also displays a high degree of variability (Figure 11.13). The 1962 year class is particularly large, more than twice any other estimated recruitment. Recruitment appears to be lower in early 1990s than in the mid-1980s, but the recent observations are based upon cohorts that have not been extensively observed in the available data.

Projections and Harvest Alternatives

The reference fishing mortality rate for Pacific ocean perch is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Estimates of $F_{0.40}$, $F_{0.35}$, and $SPR_{0.40}$ were obtained from a spawner-per-recruit analysis. Assuming that the average recruitment from the 1977-2000 year classes estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{0.40}$ is calculated as the product of $SPR_{0.40}$ * equilibrium recruits, and this quantity is 130,358 t. The year 2004 spawning stock biomass is estimated as 122,525 t. Since reliable estimates of the 2004 spawning biomass (B), $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and $B<B_{0.40}$ (122,525 t < 130,358, t), POP reference fishing mortality is defined in tier 3b. For this tier, F_{ABC} is constrained to be ≤ $F_{0.40}$, and F_{OFL} is constrained to be ≤ $F_{0.35}$; the values of $F_{0.40}$ and $F_{0.35}$ are 0.0480 and 0.057, respectively. Under the guidelines of tier 3b of Amendment 56, we calculate the F_{ABC} as $\{F_{0.40}$ x $(SPB_{2002}/SPB_{0.40}$ - 0.05)/(1-0.05)}. This procedure produces an F_{ABC} of 0.045 and an ABC estimate for the Aleutian Islands region of approximately 13,297 t. This ABC is approximately 1,774 t lower than last year's recommendation of 15,071 t. The estimated catch level for year 2004 associated with the overfishing level of F = 0.054 is 15,761 t. A summary of these values is below.

2004 SSB estimate (B)	=	122,525 t
$B_{0.40}$	=	130,358 t
$F_{0.40}$	=	0.048
F_{ABC}	=	0.045
$F_{0.35}$	=	0.057
F_{OFL}	=	0.054

Harvest rates producing maximum sustainable yield for many stocks of rockfish off the west coast of the continental U.S. may be lower than the commonly used $F_{0.40}$ values, based upon a Baysian meta-analysis of stock-recruitment relationships (Dorn 2002). For example, the MSY rate for the west coast stock of POP was $F_{0.70}$. However, Dorn's analysis also indicates that eastern Bering Sea and Aleutian Islands POP were the most resilient stocks in his analysis, and produced MSY harvest rates of less that $F_{0.30}$. Thus, the $F_{0.40}$ harvest rates used in this assessment appear to be appropriate, although examination of the spawner-recruit relationships should be re-evaluated as more data is collected.

Projections and Harvest Alternatives

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2003 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2004 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2003. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2004, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In previous assessments, this scenario has allowed the *max* F_{ABC} to be adjusted downward by a constant fraction corresponding to a value recommended in the stock assessment. For this assessment, this scenario computes a harvest rate corresponding to a downward adjustment of the $F_{35\%}$ based upon uncertainty correction factors used in Alternative 3.2 of the PSEIS. The F_{ABC} was then the minimum of the downward adjusted $F_{35\%}$ and the *max* F_{ABC}.

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 1998-2002 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

For scenario 2, the uncertainty correction factor used was that derived for GOA northern rockfish, which was 0.965. This uncertainty factor did not lower the $F_{35\%}$ below the *max* F_{ABC}, thus scenario 2 is equivalent to scenario 1.

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether the Pacific ocean perch stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above its MSY level in 2004, then the stock is not overfished.)

Scenario 7: In 2004 and 2005, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2006 under this scenario, then the stock is not approaching an overfished condition.)

The projections of the mean spawning stock biomass, fishing mortality rate, and harvest for these scenarios are shown in Table 11.12. The results of these two scenarios indicate that the BSAI Pacific ocean perch stock is neither overfished or approaching an overfished condition. With regard to assessing the current stock level, the expected stock size in the year 2004 of scenario 6 is 1.07 times its $B_{35\%}$ value of 114,063 t. With regard to whether Pacific ocean perch is likely to be overfished in the future, the expected stock size in 2006 of scenario 7 is 1.06 times the $B_{35\%}$ value.

OTHER CONSIDERATIONS

This combination of the eastern Bering Sea and Aleutian Islands management areas motivates consideration of the criteria to be used to divide the ABC among the areas. Because the AI trawl survey spans the two management areas, one option is to use the proportional survey biomass from the two areas to partition the ABCs. The average biomass from 1991-2002 in the AI management area is 454,656 t, whereas the average from the southern Bering Sea is 13,399 t; thus 97% of the estimated Aleutians Islands survey biomass occurs in the Aleutian Islands management area. Because the Aleutian Islands survey does not cover the EBS slope, it may be useful to consider the 2002 EBS slope survey biomass of

72,685 t. The combined biomass in the EBS management area (13,399 t +72,685 t=86,084 t) is 16% of the combined BSAI biomass from both surveys of 540,740 t. Thus, it is recommended that 16% of the ABC, or 2,128 t, be allocated to the EBS region and 84%, or 11,169 t, be allocated to the AI region.

As in previous years, it is recommended that the Aleutians Islands portion of the ABC be partitioned among management subareas in proportion to the estimated biomass. The five most recent trawl surveys (1991, 1994, 1997, 2000, and 2002; Table 11.13), indicate that the average POP biomass was distributed in the Aleutian Islands region as follows:

	Biomass (%)
Eastern subarea (541):	27.6%
Central subarea (542):	26.3%
Western subarea (543):	46.1%
Total	100%

Under these proportions, the recommended ABCs are 3,083 t for area 541, 2,937 t for area 542, and 5,149 t for area 543.

ECOSYSTEM CONSIDERATIONS

Pacific ocean perch feed upon calanoid copepods, euphausids, myctophids, and other miscellaneous prey (Yang 1996). Calaniod copepods and euphausids form the largest proportion of the diet, with the proportion of myctophids increasing with increasing POP size (Yang 2003).

The POP fishery has little effect on other target species in the Aleutian Islands, with the large majority of catch consisting of POP. For example, in 2002 POP were the dominant species caught within the POP fishery, with 8,692 t of the 2002 total fishery catch of 11,731 t. The 2002 catch of Atka mackerel in the POP fishery was 1,058 t, and Atka mackerel have often been the second most prominent species in the fishery in recent years.

The Pacific ocean perch fishery has annually caught less than less than 100 t of each of the non-target species since 2000, with the most prominent non-target catches in 2002 being grenadiers (85 t), sponge (76 t), skates (70 t), and sculpins (58 t). The proportions of the 2002 total catch of these non-target species were 78%, 45%, 29%, and 6%, respectively.

SUMMARY

The management parameters for Pacific ocean perch as presented in this assessment are summarized as follows:

Quantity	Value
M	0.05
Tier	3b
Year 2004 Total Biomass	348,690 t
Year 2004 Spawning stock biomass	122,525 t
$B_{100\%}$	325,894 t
$B_{40\%}$	130,358 t
$B_{35\%}$	114,063 t
F_{OFL}	0.054
Maximum F_{ABC}	0.045
Recommended F_{ABC}	0.045
OFL	15,761 t
Maximum allowable ABC	13,297 t
Recommended ABC	13,297 t

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Table 11.1. Estimated removals of Pacific ocean perch (*S. alutus*, t) since implementation of the Magnuson Fishery Conservation and Management Act of 1976.

	Eastern Bering Sea			Aleutian Islands			BSAI
Year	Foreign	JVP	DAP	Foreign	JVP	DAP	Total catch
1977	2,654	--	--	8,080	--	--	10,734
1978	2,221	--	--	5,286	--	--	7,507
1979	1,723	--	--	5,487	--	--	7,210
1980	1,050	47	--	4,700	Tr	--	5,797
1981	1,221	1	--	3,618	4	--	4,844
1982	212	3	8	1,012	2	--	1,237
1983	116	97	7	272	8	--	500
1984	156	134	1,122	356	273	2	2,043
1985	35	32	629	Tr	215	72	983
1986	16	117	375	Tr	160	98	766
1987	5	50	768	0	500	391	1,714
1988	0	51	874	0	1,513	362	2,800
1989	0	31	2,570	0	Tr	2,101	4,702
1990	0	0	6,344	0	0	11,838	18,182
1991	0	0	5,339	0	0	2,831	8,170
1992	0	0	3,309	0	0	10,278	13,587
1993	0	0	3,746	0	0	13,330	17,076
1994	0	0	1,687	0	0	10,865	12,552
1995	0	0	1,207	0	0	10,303	11,510
1996	0	0	2,855	0	0	12,827	15,682
1997	0	0	817	0	0	12,648	13,465
1998	0	0	1,017	0	0	9,051	10,068
1999	0	0	381	0	0	11,880	12,261
2000	0	0	451	0	0	8,577	9,028
2001	0	0	888	0	0	7,924	8,812
2002	0	0	630	0	0	9899	10,529
2003*	0	0	1177	0	0	12,366	13,543

Tr = trace, JVP = Joint Venture Processing, DAP = Domestic Annual Processing.
Source: PacFIN, NMFS Observer Program, and NMFS Alaska Regional Office.
*Estimated removals through September 27, 2003.

Table 11.2. Estimated retained and discarded catch (t), and percent discarded, of Pacific ocean perch from the eastern Bering Sea (EBS) and Aleutian Islands (AI) regions.

	EBS			AI			BSAI		
			Percent			Percent			Percent
Year	Retained	Discarded	Discarded	Retained	Discarded	Discarded	Retained	Discard	Discarded
1990	5,069	1,275	20.10	10,288	1,551	13.10	15,357	2,826	15.54
1991	4,112	1,227	22.98	1,851	980	34.62	5,963	2,207	27.01
1992	2,784	525	15.87	8,686	1,592	15.49	11,470	2,117	15.58
1993	2,602	1,144	30.54	11,438	1,892	14.19	14,040	3,036	17.78
1994	1,281	406	24.07	9,491	1,374	12.65	10,772	1,780	14.18
1995	839	368	30.49	8,603	1,700	16.50	9,442	2,068	17.97
1996	2,522	333	11.66	9,832	2,995	23.35	12,354	3,328	21.22
1997	539	278	34.03	10,855	1,793	14.18	11,394	2,071	15.38
1998	821	201	19.67	8,030	940	10.48	8,851	1,141	11.42
1999	247	134	35.17	10,406	1,473	12.40	10,653	1,607	13.11
2000	229	221	49.11	7,844	734	8.56	8,073	955	10.58
2000	229	221	49.11	7,844	734	8.56	8,073	955	10.58
2001	396	492	55.41	6,586	1,338	16.89	6,982	1,830	20.77
2002	280	350	55.55	8665	1234	12.47	8,945	1584	15.04

Source: NMFS Alaska Regional Office

Table 11.3. Estimated catch (t) of Pacific ocean perch in Aleutian Islands and eastern Bering Sea trawl surveys, and the eastern Bering Sea hydroacoustic survey.

		Area	
Year	AI	BS	BS-Hydroacoustic
1977		0.01	
1978		0.13	0.01
1979		3.08	
1980	71.47	0.00	
1981		13.98	
1982	0.24	12.09	
1983	133.30	0.16	
1984		0.00	
1985		98.57	
1986	164.54	0.00	
1987		0.01	
1988		10.43	
1989		0.00	
1990		0.02	0.01
1991	73.57	2.76	0.00
1992		0.38	0.00
1993		0.01	0.00
1994	112.79	0.00	0.02
1995		0.01	0.01
1996		1.18	0.00
1997	177.94	0.73	0.15
1998		0.01	0.00
1999		0.19	0.00
2000	140.82	22.90	0.45
2001		0.11	
2002	130.31	13.18	0.31
2003		7.55	

Table 11.4. Proportional catch (by weight) of Aleutians Islands POP in the foreign/joint venture fisheries and the domestic fishery by depth.

Depth	Foreign and JV (1977-1988)	Domestic (1990-2002)
0-99	0.03	0.00
100-199	0.34	0.22
200-299	0.49	0.65
300-399	0.13	0.12
400-499	0.01	0.01
500-599	0.00	0.00
≥501	0.00	0.00
Observed catch	1,638	95,557
Total Catch	31,486	132,881
Sampling ratio	0.05	0.72

Table 11.5. Proportional catch (by weight) of Aleutians Islands POP in the foreign and joint venture fisheries and the domestic fishery by management area.

Area	Foreign and JV (1977-1988)	Domestic (1990-2002)
541	0.46	0.41
542	0.27	0.24
543	0.26	0.35
Observed catch	1,638	95,577
Total Catch	31,486	132,881
Sampling ratio	0.05	0.72

Table 11.6. Length measurements and otoliths read from the EBS and AI POP fisheries, from Chikuni (1975) and NORPAC Observer database.

	Length Measurements			Otoliths read		
Year	EBS	AI	Total	EBS	AI	Total
1964	24,150	55,599	79,749			
1965	14,935	66,120	81,055			
1966	26,458	25,502	51,960			
1967	48,027	59,576	107,603			
1968	38,370	36,734	75,104			
1969	28,774	27,206	55,980			
1970	11,299	27,508	38,807			
1971	14,045	18,926	32,971			
1972	10,996	18,926	29,922			
1973	1		1**			
1974	84		84**	84		84**
1975	1		1**	125		125**
1976	50		50**	114	19	133**
1977	1,059	2,778	3,837*	139	404	543
1978	7,926	7,283	15,209*	583	641	1,224
1979	1,045	10,921	11,966*	248	353	601
1980		3,995	3,995*		398	398
1981	1,502	7,167	8,669*	78	432	510
1982		4,902	4,902*		222	222
1983	232	441	673			
1984	1,194	1,210	2,404	72		72**
1985	300		300**	160		160**
1986		100	100**		99	99**
1987	11	384	395	11		11**
1988	306	1,366	1,672			
1989	957	91	1,048		19	19**
1990	22,228	47,198	69,426*	144	184	328
1991	8,247	8,221	16,468			
1992	13,077	24,932	38,009			
1993	8,379	26,433	34,812			
1994	2,654	11,546	14,200			
1995	272	11,452	11,724			
1996	2,967	13,146	16,113			
1997	143	10,402	10,545			
1998	989	11,106	12,095*		823	823
1999	289	3,839	4,128			
2000	284	3,382	3,666*		487	487
2001	327	2,388	2,715*		258	258
2002	78	3,674	3,749			

*Used to create age composition.
**Not used.

Table 11.7. Pacific ocean perch estimated biomass (t) from the Aleutian Islands trawl surveys, by management area.

	Southern Bering Sea			Aleutian Islands			Total Aleutian Islands Survey		
Year	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1979									
1980	6003	9966	1.66	109022	27670	0.25	115025	29410	0.26
1981									
1982									
1983	97478	89946	0.92	144080	26338	0.18	241558	93723	0.39
1984									
1985									
1986	49562	26433	0.59	220614	39909	0.18	270176	47869	0.18
1987									
1988									
1989									
1990									
1991	1501	758	0.51	349592	79318	0.23	351093	79322	0.23
1992									
1993									
1994	18217	11685	0.64	365401	87600	0.24	383618	88376	0.23
1995									
1996									
1997	12099	7008	0.58	613174	96405	0.16	625272	96659	0.15
1998									
1999									
2000	18870	10150	0.54	492836	89535	0.18	511706	90109	0.18
2001									
2002	16311	6637	0.41	452277	76693	0.17	468588	76979	0.16

Table 11.8. Length measurements and otoliths read from the Aleutian Islands surveys.

Year	Length measurements	Otoliths read
1980	20796	872
1983	22873	2299
1986	14804	1860
1991	14262	807
1994	18922	788
1997	22823	1172
2000	21972	1219
2002	18980	337

Table 11.9. Negative log likelihood fits of various model components for BSAI POP models with varying levels of the standard deviation of log recruits.

Likelihood	Standard deviation of log recruits			
Component	0.5	0.75	1.0	no recruitment likelihood
Recruitment	6.92	15.37	22.01	0.00
AI survey biomass	2.63	2.82	2.90	3.46
CPUE	24.64	23.42	23.09	21.76
Catch	0.00	0.00	0.00	0.00
Fishing mortality penalty	7.17	6.70	6.53	6.02
fishery biased age comps	10.46	12.74	14.06	15.63
fishery unbiased age comps	32.72	32.05	31.66	30.39
fishery length comps	195.81	180.72	177.60	170.84
AI survey age comps	53.53	50.83	49.79	49.26
- ln likelihood	314.25	304.03	306.25	275.56
Average Effective Sample Size				
Fishery biased ages	146.23	111.94	95.50	80.99
Fishery unbiased ages	54.83	57.77	58.51	62.51
Fishery lengths	241.53	277.65	292.13	341.76
AI Survey ages	62.19	63.21	63.13	63.35
Average Sample Sizes				
Fishery biased ages	25.75	25.75	25.75	25.75
Fishery unbiased ages	20.50	20.50	20.50	20.50
Fishery lengths	155.04	155.04	155.04	155.04
AI Survey ages	33.00	33.00	33.00	33.00
Root Mean Squared Error				
CPUE Index	0.79	0.77	0.77	0.76
survey	0.18	0.19	0.19	0.20
recruitment	0.61	0.78	0.92	4.97

Table 11.10. Estimated time series of POP total biomass (t), spawner biomass (t), and recruitment (thousands) for each region.

	Total Biomass (ages 3+)		Spawner Biomass (ages 3+)		Recruitment (age 3)	
	Assessment Year		Assessment Year		Assessment Year	
Year	2003	2002	2003	2002	2003	2002
1960	561,754	561,921	115,790	114,107	27,855	25,197
1961	609,322	609,986	139,626	138,315	203,747	204,876
1962	601,148	602,248	156,521	155,775	46,136	47,598
1963	612,325	613,595	182,731	182,527	29,454	28,006
1964	601,371	602,833	195,730	195,988	152,649	153,113
1965	541,369	543,354	172,515	173,087	455,916	461,176
1966	452,259	454,386	136,392	137,215	26,766	25,272
1967	381,415	383,588	101,630	102,467	39,021	37,492
1968	343,283	345,892	78,169	78,942	98,284	102,591
1969	296,601	299,344	62,817	63,683	26,579	25,162
1970	267,340	270,143	57,486	58,465	25,659	25,077
1971	207,331	210,203	45,518	46,450	25,769	25,712
1972	190,507	193,455	45,854	46,873	25,123	25,289
1973	163,215	166,274	42,616	43,728	27,233	28,272
1974	158,324	161,484	45,053	46,253	23,263	23,767
1975	130,502	133,858	38,442	39,683	26,349	27,824
1976	112,862	116,422	33,894	35,180	20,524	21,390
1977	90,925	94,731	26,555	27,880	21,236	21,942
1978	88,399	92,574	25,160	26,530	37,263	39,715
1979	92,616	97,375	24,938	26,377	71,533	75,567
1980	99,143	104,387	24,792	26,307	67,753	68,583
1981	111,318	117,772	25,151	26,749	92,588	102,460
1982	123,164	130,402	26,285	28,015	35,573	34,954
1983	140,054	147,964	29,623	31,544	47,361	46,358
1984	165,824	175,759	34,091	36,207	143,137	160,916
1985	186,794	197,876	39,598	42,080	44,615	42,298
1986	209,979	222,267	46,171	49,003	59,282	60,277
1987	239,160	253,396	54,143	57,364	128,067	139,545
1988	264,486	279,932	63,977	67,865	58,403	56,418
1989	291,020	308,405	73,611	78,082	93,774	104,434

Table 11.10, continued.

	Total Biomass (ages 3+)		Spawner Biomass (ages 3+)		Recruitment (age 3)	
	Assessment Year		Assessment Year		Assessment Year	
Year	2003	2002	2003	2001	2003	2002
1990	313,356	332,277	83,112	88,212	54,562	56,301
1991	321,639	342,181	88,664	94,520	72,836	77,332
1992	336,503	358,208	97,354	103,904	35,540	34,892
1993	342,519	365,232	104,390	111,747	24,273	24,810
1994	341,462	364,851	109,384	117,449	19,908	19,361
1995	342,314	365,758	115,974	124,799	24,000	19,099
1996	341,632	367,803	121,896	131,368	23,869	
1997	337,200	364,671	124,759	134,769		
1998	334,998	363,620	127,133	137,594		
1999	336,138	365,625	129,158	139,833		
2000	335,933	366,021	128,665	139,935		
2001	339,898	370,265	128,968	140,676		
2002	344,528	374,809	128,698	140,832		
2003	348,114		127,582			

Table 11.11. Estimated numbers (millions) of Pacific ocean perch in the BSAI region

	Age																						
Year	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25+
1960	27.9	19.2	22.0	23.9	24.3	914.5	21.8	19.8	17.9	16.3	15.0	13.9	12.9	12.0	11.3	10.7	10.2	9.5	9.0	8.6	8.3	7.9	52.7
1961	203.7	26.5	18.2	21.0	22.7	23.0	860.1	20.5	18.6	16.8	15.3	14.1	13.0	12.1	11.3	10.6	10.0	9.6	8.9	8.4	8.1	7.8	57.0
1962	46.1	193.8	25.2	17.3	19.6	20.3	20.1	750.1	17.9	16.2	14.7	13.4	12.3	11.4	10.6	9.9	9.3	8.8	8.3	7.7	7.4	7.1	56.5
1963	29.5	43.9	184.3	24.0	16.4	18.2	18.7	18.4	687.3	16.4	14.8	13.5	12.2	11.2	10.4	9.7	9.0	8.5	8.0	7.6	7.1	6.7	58.2
1964	152.6	28.0	41.7	175.1	22.5	14.7	15.9	16.3	16.1	599.8	14.3	12.9	11.7	10.7	9.8	9.1	8.5	7.9	7.4	7.0	6.7	6.2	56.7
1965	455.9	145.2	26.6	39.5	159.9	17.9	11.0	11.8	12.1	11.9	444.3	10.6	9.6	8.7	7.9	7.3	6.7	6.3	5.8	5.5	5.2	4.9	46.6
1966	26.8	433.7	138.1	25.2	35.6	120.8	12.4	7.5	8.1	8.2	8.1	303.7	7.2	6.6	5.9	5.4	5.0	4.6	4.3	4.0	3.8	3.5	35.2
1967	39.0	25.5	412.3	130.6	22.6	26.3	80.9	8.2	5.0	5.3	5.5	5.4	200.8	4.8	4.3	3.9	3.6	3.3	3.0	2.8	2.6	2.5	25.6
1968	98.3	37.1	24.2	390.0	117.4	16.9	18.0	54.7	5.5	3.4	3.6	3.7	3.6	135.6	3.2	2.9	2.7	2.4	2.2	2.1	1.9	1.8	19.0
1969	26.6	93.5	35.3	22.9	347.2	84.1	10.9	11.4	34.6	3.5	2.1	2.3	2.3	2.3	85.9	2.0	1.9	1.7	1.5	1.4	1.3	1.2	13.1
1970	25.7	25.3	88.9	33.4	20.9	275.4	62.2	8.0	8.4	25.4	2.6	1.6	1.7	1.7	1.7	63.0	1.5	1.4	1.2	1.1	1.0	1.0	10.5
1971	25.8	24.4	24.0	84.0	29.7	14.9	176.0	39.2	5.0	5.3	16.0	1.6	1.0	1.1	1.1	1.1	39.7	0.9	0.9	0.8	0.7	0.6	7.2
1972	25.1	24.5	23.2	22.8	77.3	24.5	11.6	136.7	30.5	3.9	4.1	12.4	1.3	0.8	0.8	0.8	0.8	30.8	0.7	0.7	0.6	0.5	6.1
1973	27.2	23.9	23.3	22.0	20.7	60.9	18.0	8.5	99.3	22.1	2.8	3.0	9.0	0.9	0.6	0.6	0.6	0.6	22.4	0.5	0.5	0.4	4.8
1974	23.3	25.9	22.7	22.1	20.5	18.2	51.8	15.3	7.2	84.2	18.8	2.4	2.5	7.6	0.8	0.5	0.5	0.5	0.5	19.0	0.5	0.4	4.5
1975	26.3	22.1	24.6	21.5	20.0	15.8	12.9	36.4	10.7	5.0	59.1	13.2	1.7	1.8	5.4	0.5	0.3	0.4	0.4	0.4	13.3	0.3	3.4
1976	20.5	25.1	21.0	23.3	19.6	15.9	11.7	9.5	26.8	7.9	3.7	43.5	9.7	1.2	1.3	3.9	0.4	0.2	0.3	0.3	0.3	9.8	2.8
1977	21.2	19.5	23.8	19.9	20.9	14.5	10.7	7.8	6.3	17.7	5.2	2.4	28.8	6.4	0.8	0.9	2.6	0.3	0.2	0.2	0.2	0.2	8.3
1978	37.3	20.2	18.6	22.6	18.4	17.8	11.8	8.7	6.3	5.1	14.4	4.2	2.0	23.4	5.2	0.7	0.7	2.1	0.2	0.1	0.1	0.1	6.9
1979	71.5	35.4	19.2	17.6	21.1	16.2	15.2	10.1	7.4	5.4	4.3	12.2	3.6	1.7	19.9	4.4	0.6	0.6	1.8	0.2	0.1	0.1	6.0
1980	67.8	68.0	33.7	18.2	16.5	18.6	13.9	13.0	8.6	6.3	4.6	3.7	10.5	3.1	1.4	17.0	3.8	0.5	0.5	1.5	0.2	0.1	5.2
1981	92.6	64.4	64.7	32.0	17.1	14.8	16.3	12.2	11.4	7.5	5.5	4.0	3.2	9.1	2.7	1.3	14.8	3.3	0.4	0.4	1.3	0.1	4.6
1982	35.6	88.1	61.3	61.5	30.1	15.5	13.1	14.5	10.8	10.1	6.7	4.9	3.6	2.9	8.1	2.4	1.1	13.2	2.9	0.4	0.4	1.2	4.2
1983	47.4	33.8	83.8	58.3	58.3	28.3	14.5	12.3	13.6	10.1	9.4	6.2	4.6	3.3	2.7	7.6	2.2	1.0	12.3	2.7	0.4	0.4	5.1
1984	143.1	45.1	32.2	79.7	55.4	55.3	26.8	13.7	11.6	12.8	9.6	8.9	5.9	4.3	3.1	2.5	7.2	2.1	1.0	11.7	2.6	0.3	5.2
1985	44.6	136.2	42.9	30.6	75.6	52.1	51.7	25.1	12.8	10.9	12.0	8.9	8.3	5.5	4.0	2.9	2.4	6.7	2.0	0.9	10.9	2.4	5.1
1986	59.3	42.4	129.5	40.8	29.1	71.5	49.2	48.8	23.7	12.1	10.3	11.3	8.4	7.9	5.2	3.8	2.8	2.3	6.3	1.9	0.9	10.3	7.1
1987	128.1	56.4	40.4	123.2	38.7	27.6	67.7	46.5	46.2	22.4	11.5	9.7	10.7	8.0	7.5	4.9	3.6	2.6	2.1	6.0	1.8	0.8	16.5
1988	58.4	121.8	53.6	38.4	117.0	36.6	26.0	63.8	43.9	43.5	21.1	10.8	9.2	10.1	7.5	7.0	4.6	3.4	2.5	2.0	5.7	1.7	16.3
1989	93.8	55.6	115.9	51.0	36.4	110.2	34.4	24.4	59.9	41.2	40.9	19.8	10.2	8.6	9.5	7.1	6.6	4.4	3.2	2.3	1.9	5.3	16.9
1990	54.6	89.2	52.8	110.2	48.4	34.2	102.8	32.0	22.7	55.8	38.4	38.1	18.5	9.5	8.0	8.8	6.6	6.1	4.1	3.0	2.2	1.8	20.7
1991	72.8	51.9	84.8	50.2	103.5	43.7	30.2	90.8	28.3	20.1	49.2	33.8	33.6	16.3	8.4	7.1	7.8	5.8	5.4	3.6	2.6	1.9	19.8
1992	35.5	69.3	49.4	80.7	47.5	96.4	40.3	27.9	83.7	26.1	18.5	45.4	31.2	31.0	15.0	7.7	6.5	7.2	5.4	5.0	3.3	2.4	20.0
1993	24.3	33.8	65.9	46.9	76.1	43.7	87.4	36.5	25.3	75.8	23.6	16.7	41.1	28.3	28.1	13.6	7.0	5.9	6.5	4.8	4.5	3.0	20.3
1994	19.9	23.1	32.2	62.6	44.2	69.5	39.2	78.4	32.7	22.6	68.0	21.2	15.0	36.9	25.3	25.2	12.2	6.3	5.3	5.8	4.3	4.1	20.9
1995	24.0	18.9	22.0	30.6	59.2	40.8	63.5	35.8	71.5	29.9	20.7	62.0	19.3	13.7	33.6	23.1	23.0	11.1	5.7	4.8	5.3	4.0	22.8
1996	23.9	22.8	18.0	20.9	28.9	54.8	37.5	58.2	32.8	65.5	27.4	18.9	56.8	17.7	12.5	30.8	21.2	21.0	10.2	5.2	4.4	4.9	24.5
1997	59.3	22.7	21.7	17.1	19.7	26.5	49.7	33.9	52.6	29.7	59.3	24.7	17.1	51.4	16.0	11.3	27.9	19.2	19.0	9.2	4.7	4.0	26.6
1998	59.3	56.4	21.6	20.6	16.2	18.2	24.2	45.2	30.8	47.9	27.0	53.9	22.5	15.6	46.7	14.6	10.3	25.4	17.4	17.3	8.4	4.3	27.8
1999	59.3	56.4	53.7	20.5	19.5	15.0	16.7	22.2	41.6	28.3	44.0	24.8	49.6	20.7	14.3	43.0	13.4	9.5	23.3	16.0	15.9	7.7	29.5
2000	59.3	56.4	53.7	51.0	19.4	18.0	13.7	15.3	20.3	37.9	25.9	40.1	22.6	45.2	18.9	13.1	39.2	12.2	8.7	21.3	14.6	14.5	34.0
2001	59.3	56.4	53.7	51.0	48.3	18.1	16.6	12.6	14.1	18.7	35.0	23.8	37.0	20.9	41.7	17.4	12.0	36.1	11.3	8.0	19.6	13.5	44.7
2002	59.3	56.4	53.7	51.0	48.3	45.0	16.7	15.4	11.7	13.0	17.3	32.2	22.0	34.1	19.3	38.5	16.1	11.1	33.3	10.4	7.4	18.1	53.7
2003	59.3	56.4	53.7	51.0	48.2	44.8	41.3	15.3	14.1	10.7	11.9	15.8	29.6	20.2	31.3	17.7	35.3	14.7	10.2	30.6	9.5	6.8	65.9

NPFMC Bering Sea/Aleutian Islands SAFE

Table 11.12. Projections of BSAI spawning biomass (t), catch (t), and fishing mortality rate for each of the several scenarios. The values of $B_{40\%}$ and $B_{35\%}$ are 130,358 t and 114,063 t, respectively.

Sp. Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2003	124562	124562	124562	124562	124562	124562	124567
2004	122525	122525	123214	122837	123907	122264	122543
2005	121172	121172	124569	122695	128096	119912	121188
2006	120881	120881	126906	123554	133440	118712	120643
2007	120768	120768	129339	124560	139057	117769	119541
2008	121171	121171	132237	126073	145335	117408	119024
2009	121954	121954	135497	127976	152143	117486	118946
2010	122635	122635	138620	129773	158863	117537	118835
2011	123449	123449	141856	131705	165752	117783	118921
2012	124189	124189	144958	133548	172501	118020	119005
2013	124910	124910	147981	135356	179159	118292	119134
2014	125517	125517	150797	137015	185549	118501	119214
2015	126080	126080	153472	138586	191730	118706	119305
2016	126589	126589	155994	140056	197691	118887	119387
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2003	0.0459323	0.0459323	0.0459323	0.0459323	0.0459323	0.0459323	0.0457827
2004	0.0449909	0.0449909	0.0224954	0.034794	0	0.0535474	0.0449978
2005	0.044466	0.044466	0.0227552	0.034794	0	0.0524592	0.0444725
2006	0.0443534	0.0443534	0.023203	0.034794	0	0.0519042	0.0527973
2007	0.0443093	0.0443093	0.0236692	0.034794	0	0.0514679	0.0522875
2008	0.0444656	0.0444656	0.0240143	0.034794	0	0.0513009	0.0520485
2009	0.0447692	0.0447692	0.0240143	0.034794	0	0.0513371	0.0520123
2010	0.0450334	0.0450334	0.0240143	0.034794	0	0.0513606	0.0519609
2011	0.0453399	0.0453399	0.0240143	0.034794	0	0.0514742	0.0520006
2012	0.0455888	0.0455888	0.0240143	0.034794	0	0.0515806	0.0520339
2013	0.0457814	0.0457814	0.0240143	0.034794	0	0.0516924	0.0520763
2014	0.0458881	0.0458881	0.0240143	0.034794	0	0.0517607	0.0520819
2015	0.0459584	0.0459584	0.0240143	0.034794	0	0.0518236	0.0520908
2016	0.04601	0.04601	0.0240143	0.034794	0	0.051871	0.0520908
Catch	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2003	13543.5	13543.5	13543.5	13543.5	13543.5	13543.5	13500.3
2004	13297.2	13297.2	6721.33	10334.3	0	15760.9	13301.1
2005	13200.4	13200.4	6973.25	10478	0	15388.5	13204
2006	13261	13261	7299.67	10643.7	0	15228.9	15723.1
2007	13323.6	13323.6	7621.05	10790.3	0	15095.7	15539.4
2008	13456	13456	7906.63	10940.3	0	15063	15459.5
2009	13649.7	13649.7	8085.21	11100.4	0	15117.3	15469.7
2010	13812.7	13812.7	8248.07	11242	0	15154.7	15463.5
2011	13993.8	13993.8	8410.13	11385.4	0	15231.5	15499.7
2012	14146.2	14146.2	8561.47	11517.4	0	15301.2	15530.6
2013	14276.9	14276.9	8707.19	11644.6	0	15373.3	15567.3
2014	14366.8	14366.8	8840.42	11758	0	15421.8	15584
2015	14445.4	14445.4	8969.08	11868.7	0	15472.1	15607
2016	14510.5	14510.5	9088.93	11970.2	0	15510.8	15622.2

Table 11.13. Pacific ocean perch biomass estimates (t) from the 1991, 1994, 1997, and 2000 triennial trawl surveys broken out by the three management sub-areas in the Aleutian Islands region.

	Aleutian Islands Management Sub-Areas		
Year	Western	Central	Eastern
1991	214,137	79,911	55,545
1994	184,005	80,811	100,585
1997	225,725	166,816	220,633
2000	222,584	129,740	140,512
2002	202,124	140,358	109,795
Average	209,715	119,527	125,414
Percentage	46.1%	26.3%	27.6%

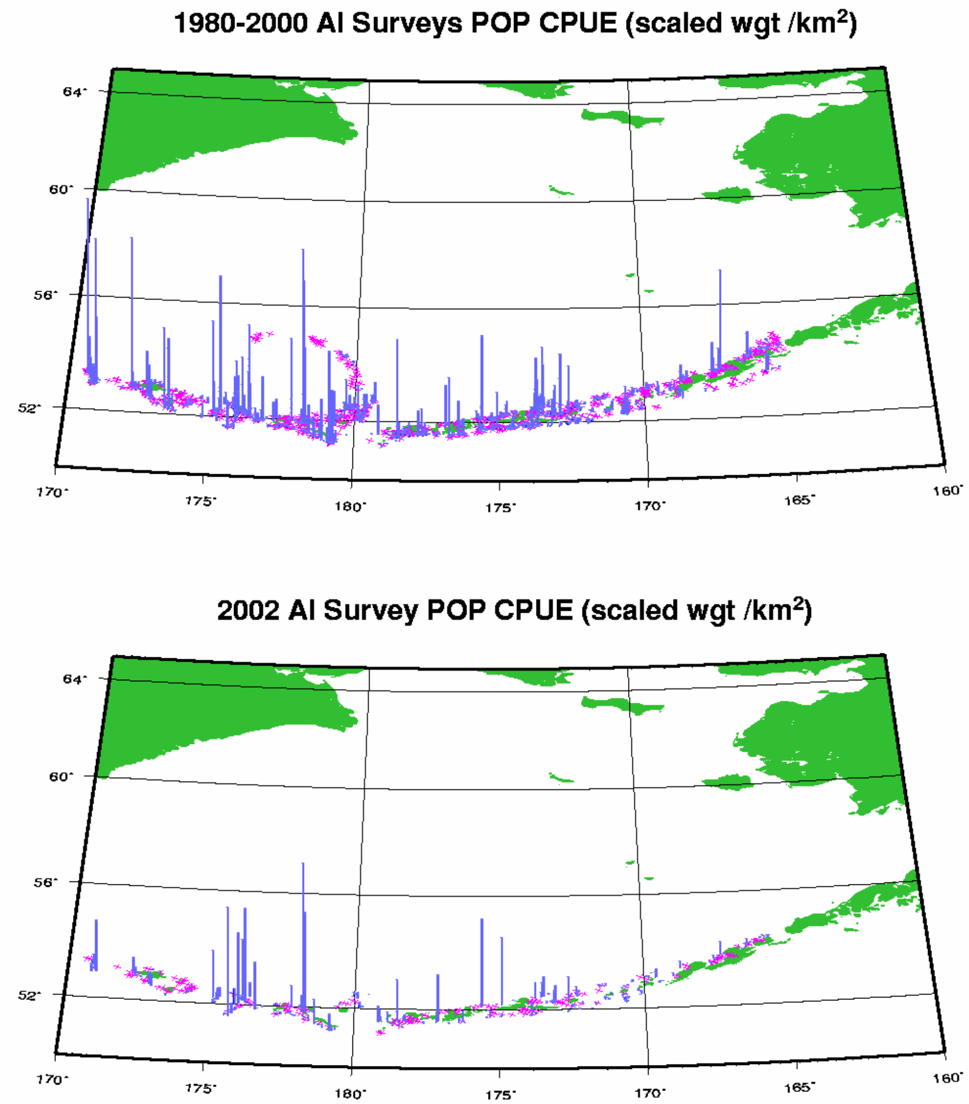

Figure 11.1. Scaled AI survey POP CPUE from 1980-2000 (top panel), and 2002 (bottom panel)

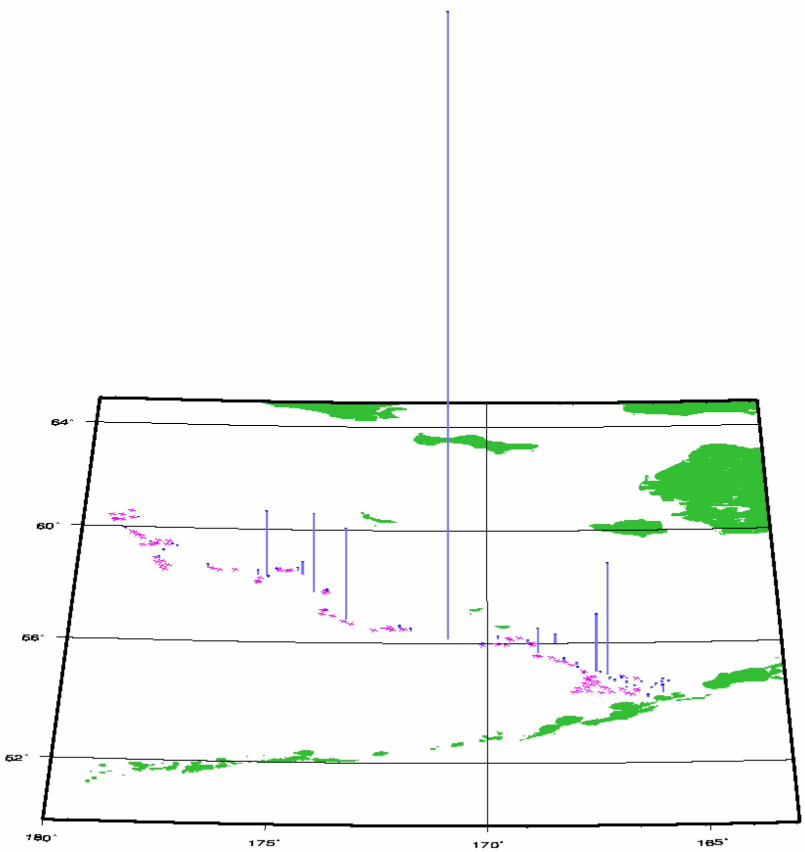

Figure 11.2. 2002 EBS Survey Pacific Ocean Perch CPUE (scaled wgt /ha)

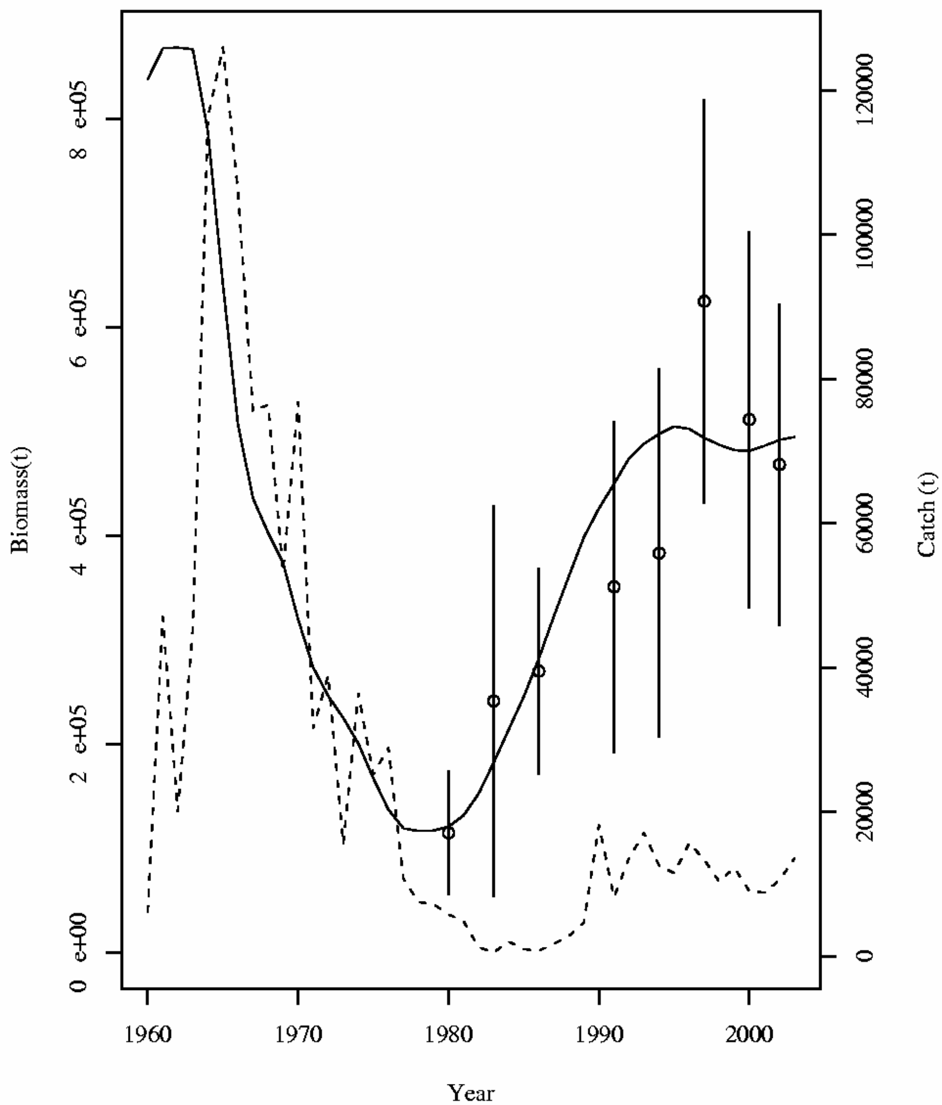

Figure 11.3. Observed AI survey biomass(data points, +/– 2 standard deviations), predicted survey biomass(solid line), and BSAI harvest (dashed line).

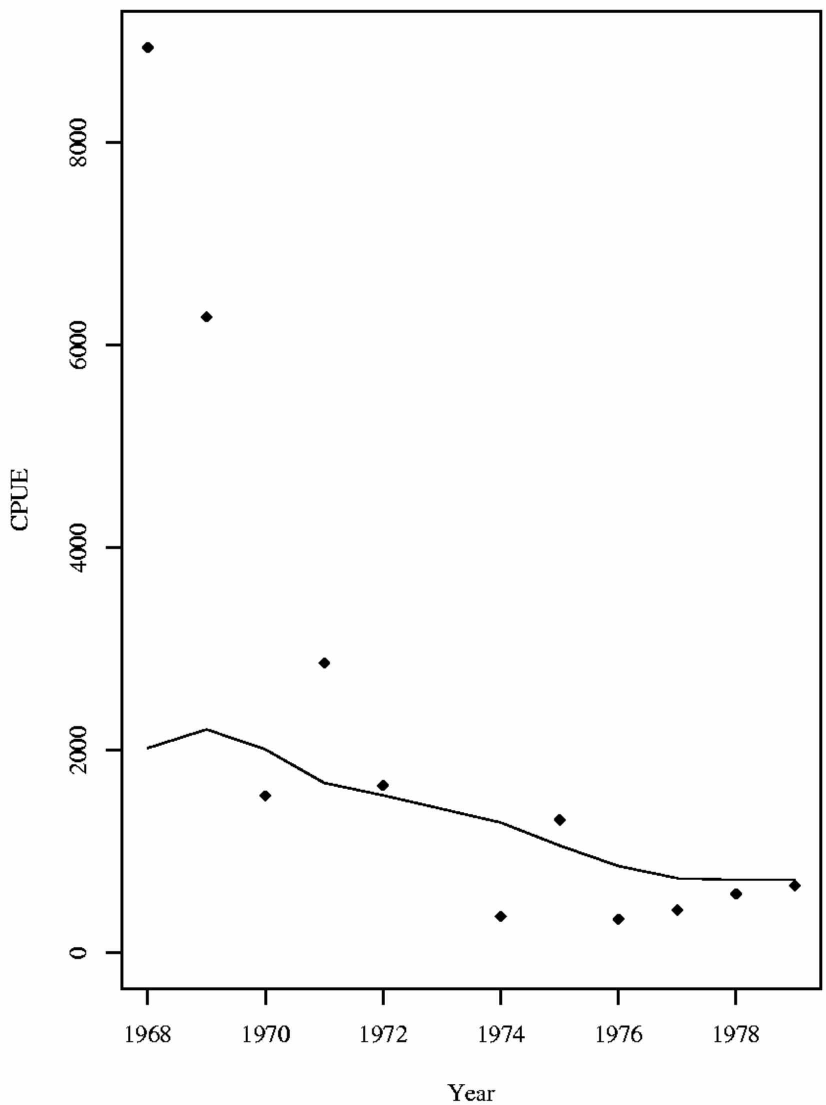

Figure 11.4. Observed AI CPUE (data points) and predicted CPUE (solid line) for BSAI POP.

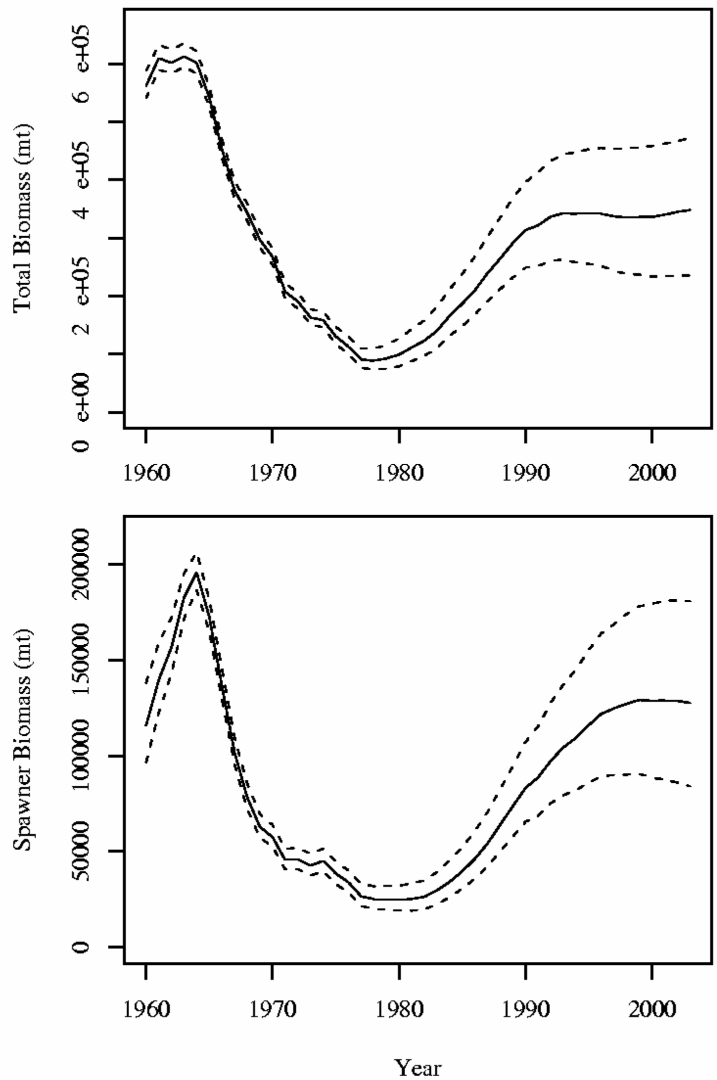

Figure 11.5. Total and spawner biomass for BSAI Pacific ocean perch, with 95% confidence intervals from MCMC integration.

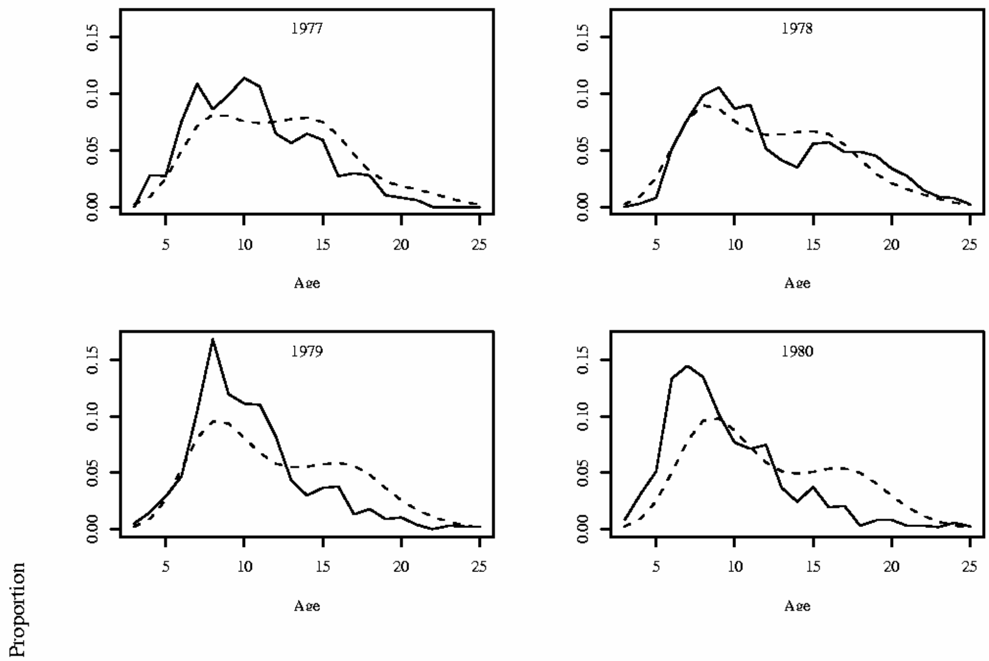

Figure 11.6. Fishery biased age composition by year (solid line = observed, dotted line = predicted)

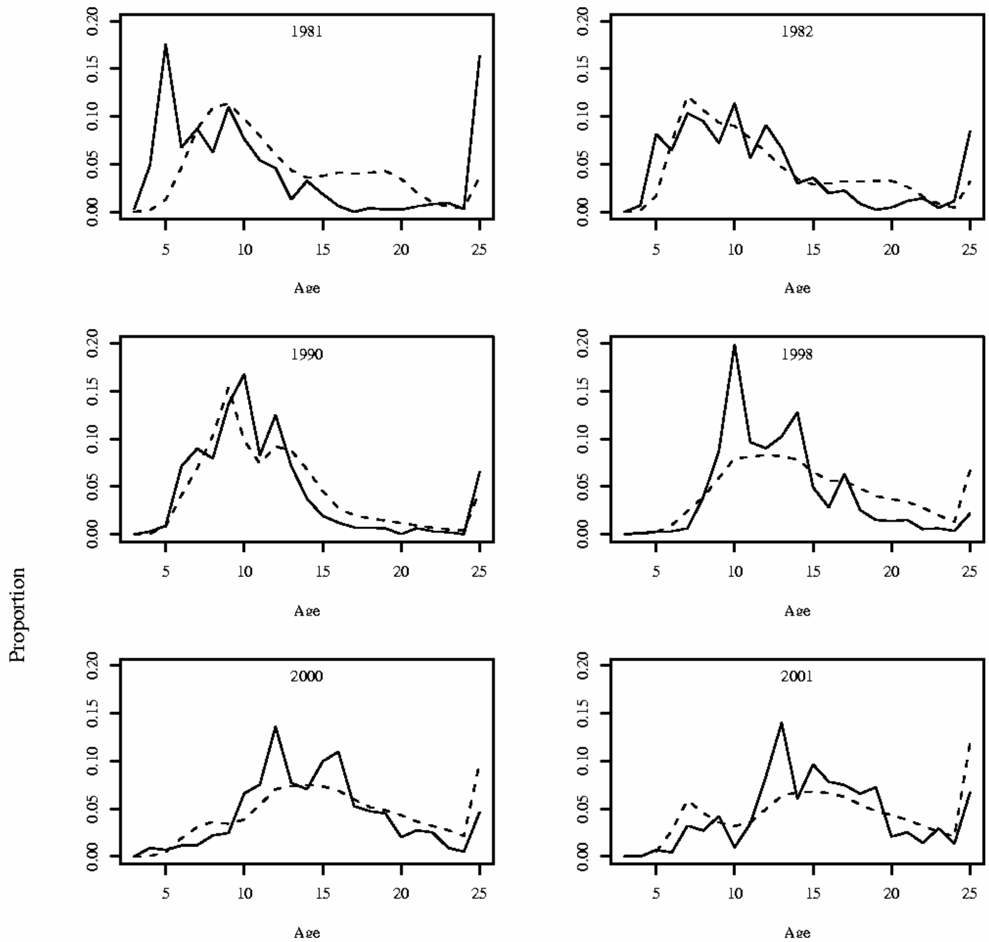

Figure 11.7. Fishery age composition by year (solid line = observed, dotted line = predicted)

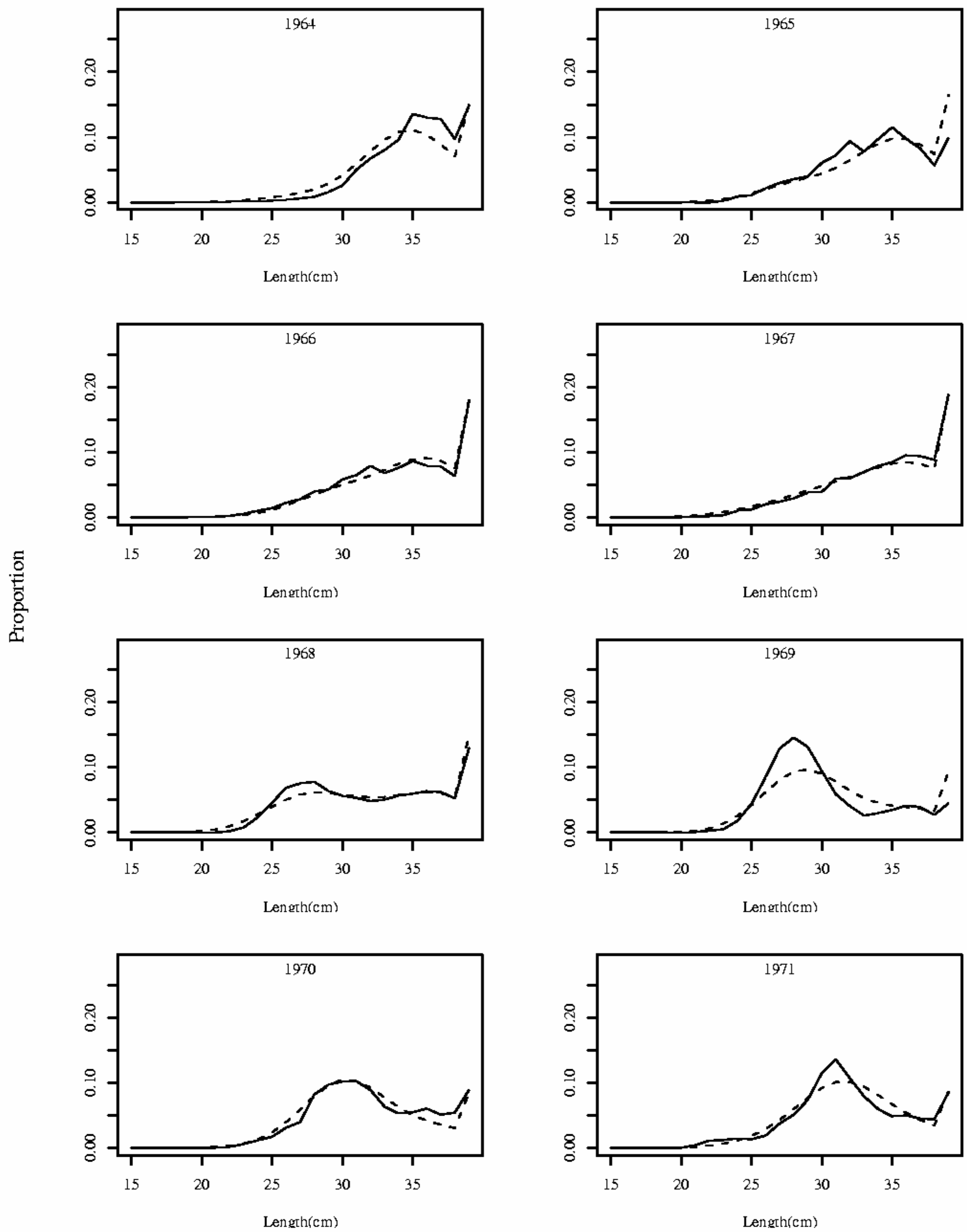

Figure 11.8. Fishery length composition by year (solid line = observed, dotted line = predicted)

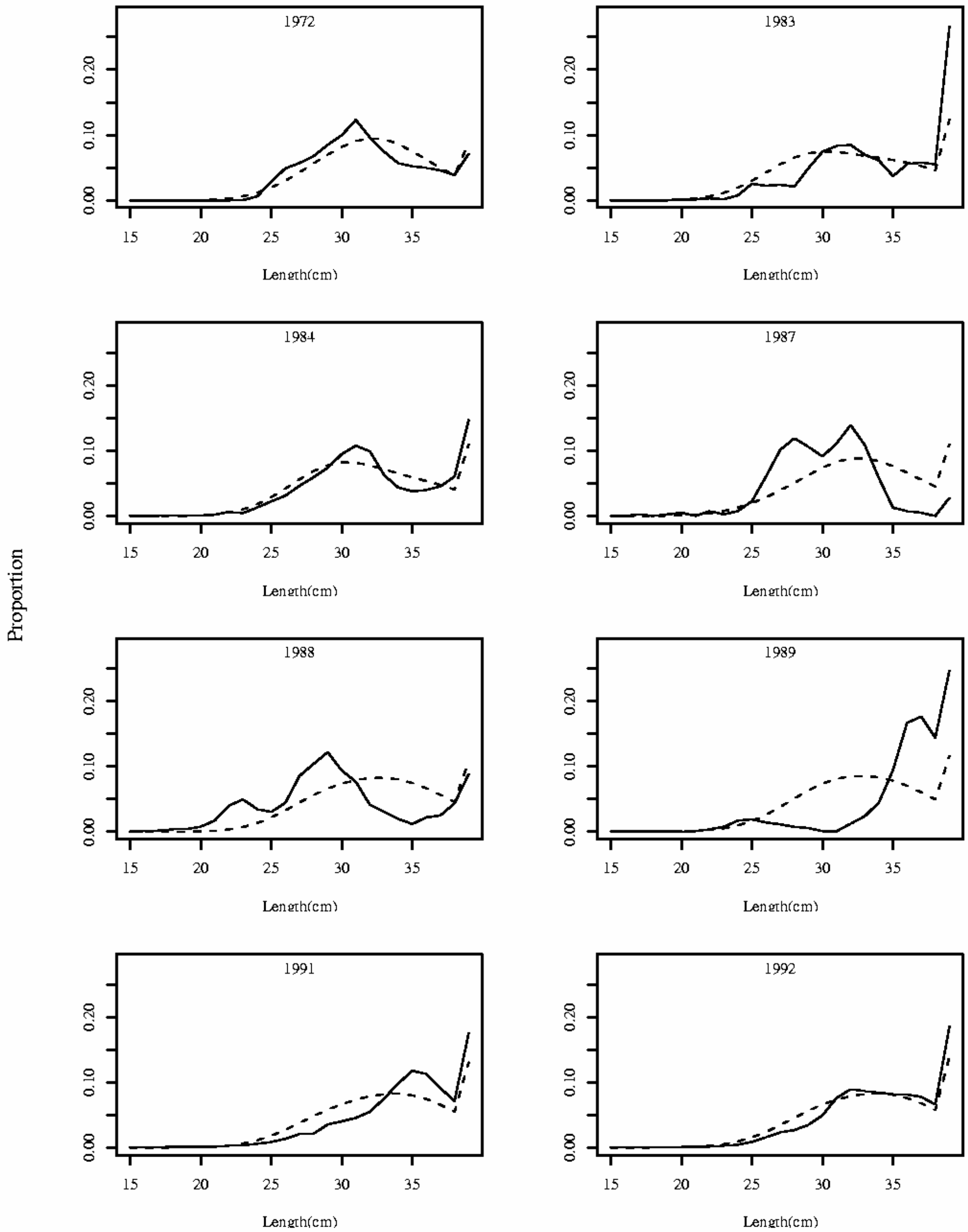

Figure 11.8 (continued). Fishery length composition by year (solid line = observed, dotted line = predicted)

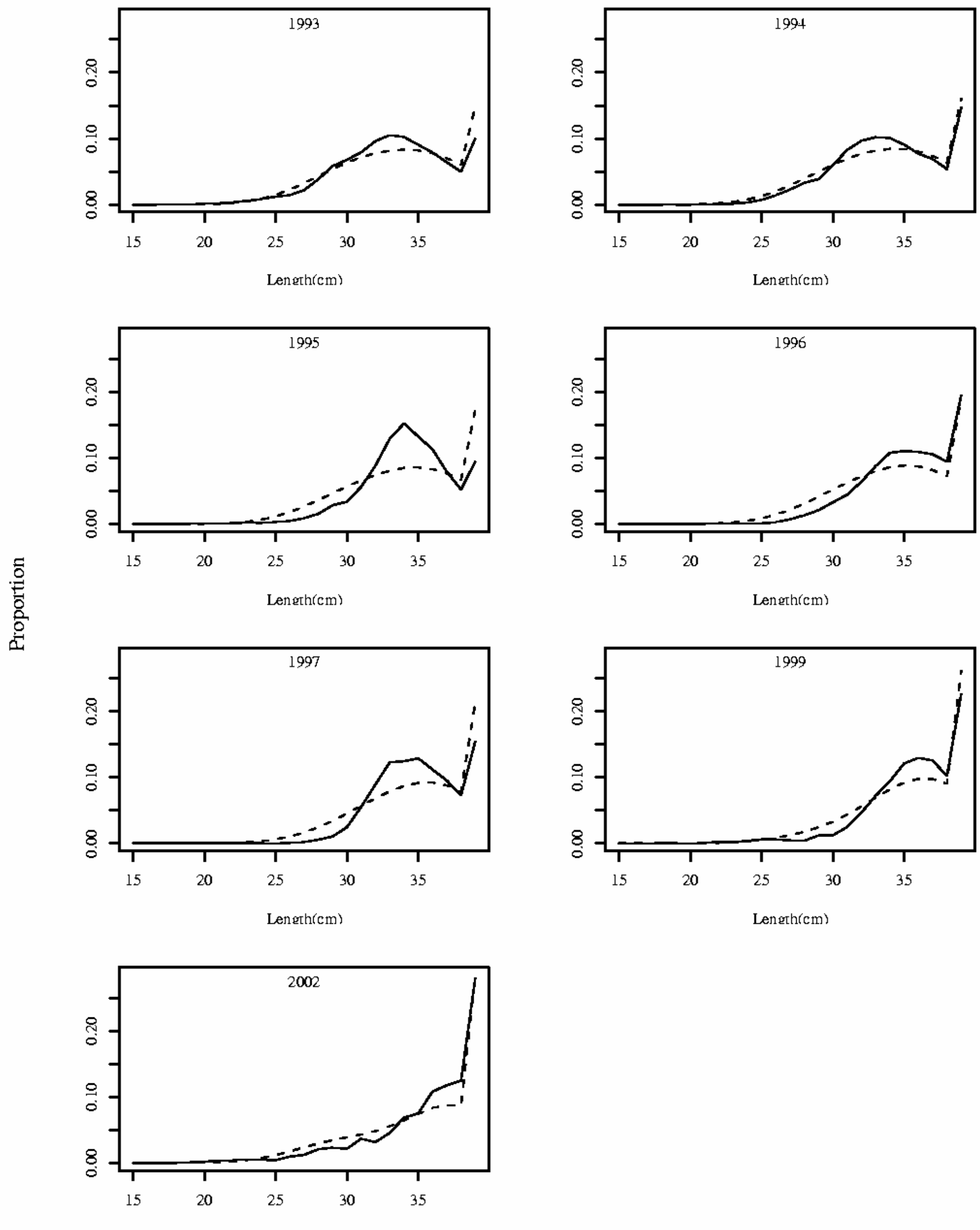

Figure 11.8 (continued). Fishery length composition by year (solid line = observed, dotted line = predicted)

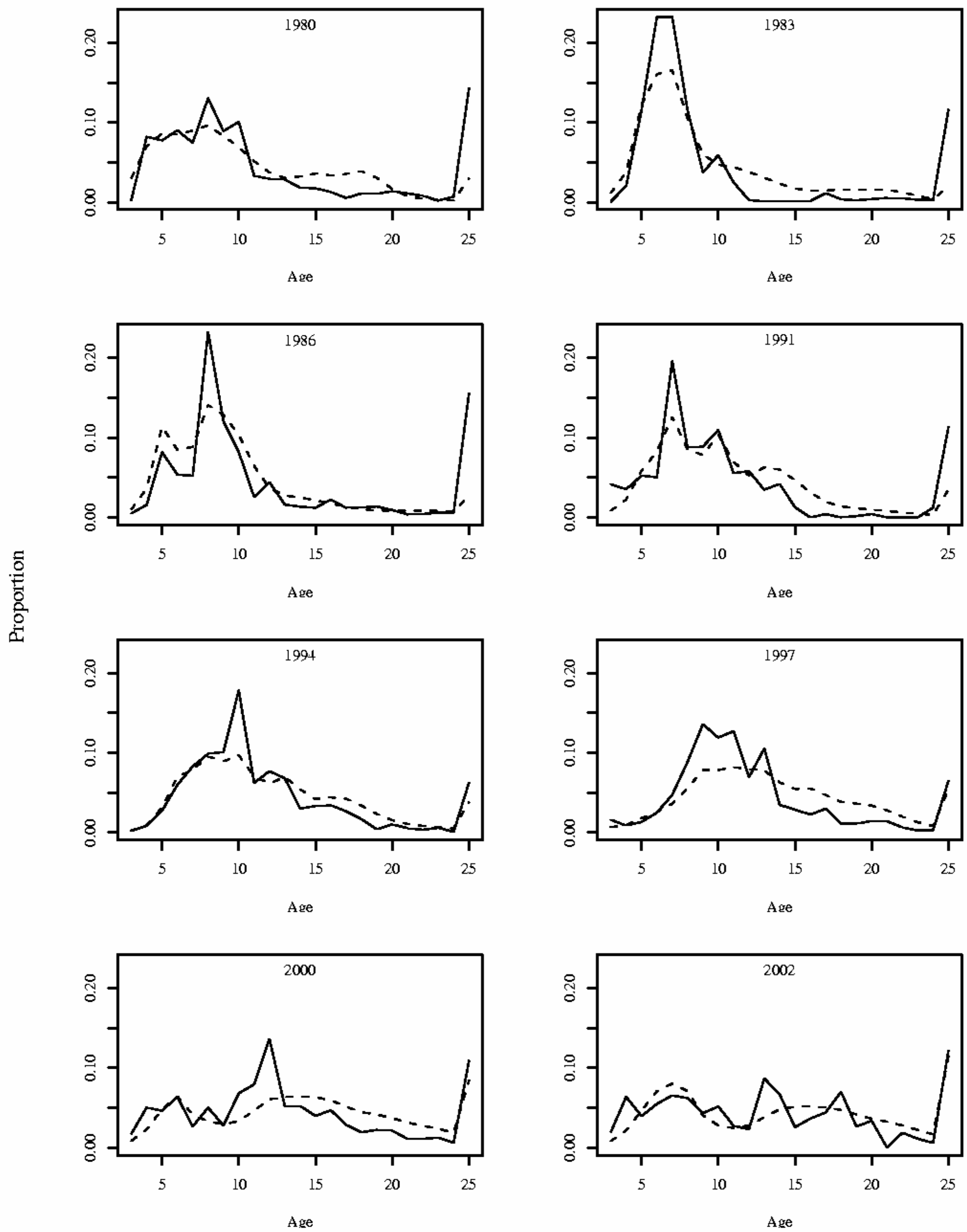

Figure 11.9. AI Survey age composition by year (solid line = observed, dotted line = predicted)

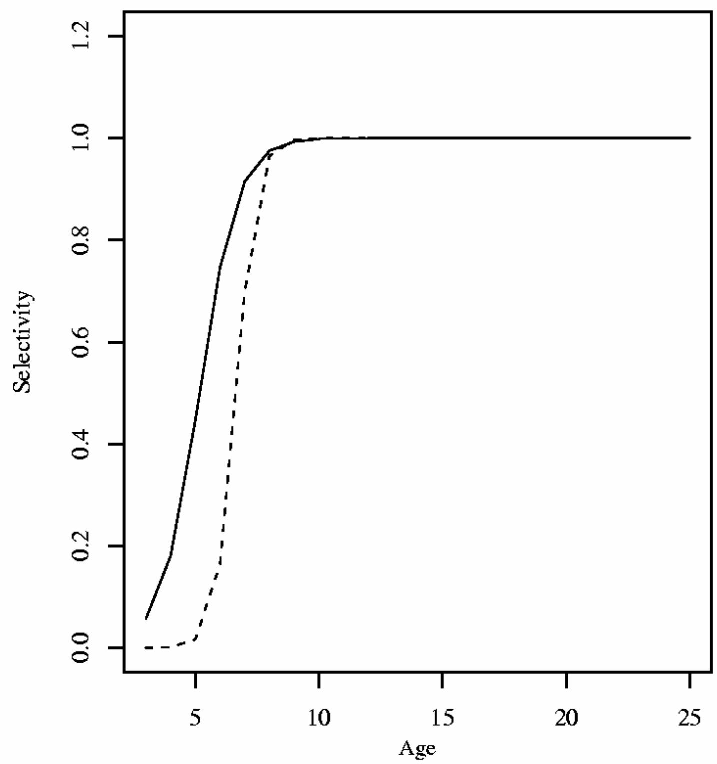

Figure 11.10. Estimated survey (solid line) and fishery (dashed line) selectivity curves for BSAI POP

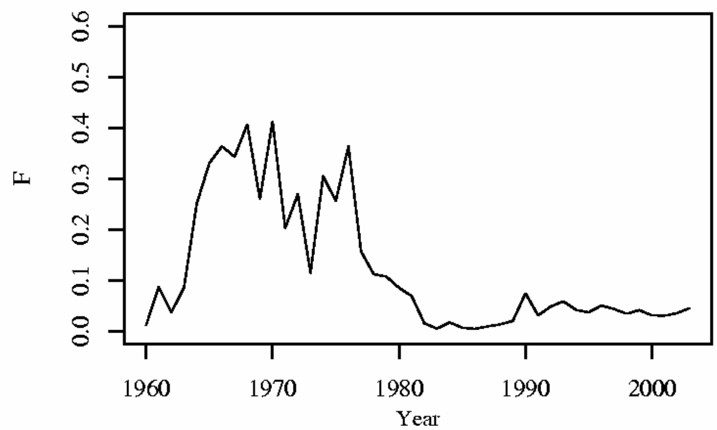

Figure 11.11. Estimated fully selected fishing mortality for BSAI POP.

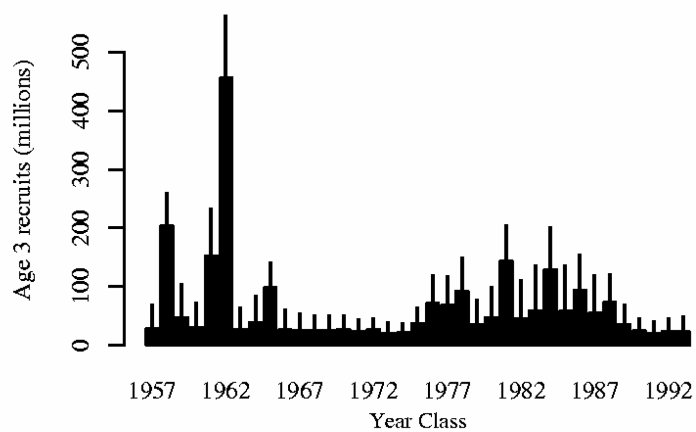

Figure 11.12. Estimated recruitment (age 3) of BSAI POP, with 95% CI limits obtained from MCMC integration.

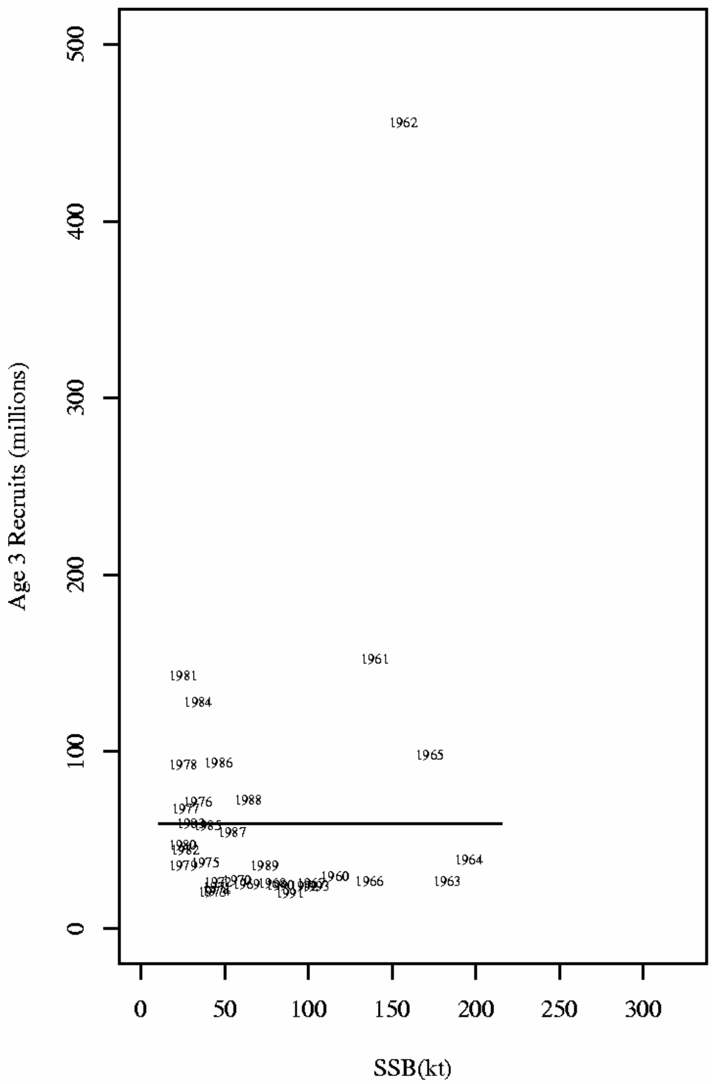

Figure 11.13. Scatterplot of BSAI POP spawner–recruit data; label is year class.